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MODEL OF DREDGING IMPACT ON DUNGENESS CRAB IN GRAYS HARBOR, WASHINGTON

by

David A. Armstrong, Thomas C. Wainwright, José Orensanz,
Paul A. Dinnel, and Brett R. Dumbauld

FINAL REPORT

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The effects of dredging on marine organisms have been an issue for several decades. Studies have shown effects on the composition of infaunal communities, including disruption and subsequent recolonization. Few attempts have been made to develop predictive models of dredging impacts on invertebrates. A few studies have focused specifically on Dungeness crab, primarily in Grays Harbor. The most recent of these studies has been aimed at quantifying crab entrainment and dredging mortality rates. The

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intent of this study was three fold: 1) to predict the numbers of crabs in various age classes that would be entrained and killed during the proposed widening and deepening of the Grays Harbor navigation channel; 2) to use those predictions to forecast losses to the commercial fishery and; 3) to modify both the dredge schedule and types of gear used in various areas (reaches) of the estuary in order to reduce predicted impact to crab.

S2. SOURCES AND USE OF DATA

The data used in this study came from a variety of sources. A framework of general Dungeness crab biology and ecology was drawn both from the general literature and from previous analyses of field studies conducted since 1980 in and near Grays Harbor.

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S1. INTRODUCTION

The effects of dredging on marine organisms have been an issue for several decades. Studies have shown effects on the composition of infaunal communities, including disruption and subsequent recolonization. Few attempts have been made to develop predictive models of dredging impacts on invertebrates. A few studies have focused specifically on Dungeness crab, primarily in Grays Harbor. The most recent of these studies has been aimed at quantifying crab entrainment and dredging mortality rates. The intent of this study was three fold: 1) to predict the numbers of crabs in various age classes that would be entrained and killed during the proposed widening and deepening of the Grays Harbor navigation channel; 2) to use those predictions to forecast losses to the commercial fishery and; 3) to modify both the dredge schedule and types of gear used in various areas (reaches) of the estuary in order to reduce predicted impact to crab.

S2. SOURCES AND USE OF DATA

The data used in this study came from a variety of sources. A framework of general Dungeness crab biology and ecology was drawn both from the general literature and from previous analyses of field studies conducted since 1980 in and near Grays Harbor.

Size-at-age and growth were estimated using a recently developed technique for analyzing size-frequency distributions; results from this technique are comparable to previous work on Dungeness crab growth. It was determined that crab settling within the estuary experience more rapid early growth than those settling in nearshore oceanic waters. A great deal of variation in growth (both within and among year classes) was observed. It was concluded that the bulk of a year class in the Grays Harbor area

will recruit to the fishery at either 3.5 or 4.5 years after settlement, depending on the conditions of its early growth.

Abundances of Dungeness crab in Grays Harbor and adjacent nearshore waters were estimated from data collected primarily in the spring and summer during a 4-year research program sponsored by the Washington Sea Grant Program. Standardized beam-trawl sampling was conducted in subtidal areas of Grays Harbor and the adjacent coast. Intertidal portions of Grays Harbor were sampled at low tide with standard quadrats. Crab populations were estimated from these data by an area-swept technique; populations were estimated separately for several geographic strata within the overall study areas. Crab abundance was seen to fluctuate considerably from year to year. Certain geographic patterns of age-class distribution were clear: young-of-the-year (0+) crab were largely concentrated in intertidal areas; age 1+ and older crab occurred in the subtidal areas of Grays Harbor and nearshore, and their relative abundance in these two areas changed dramatically from year to year. Crabs larger than 100 mm carapace width were generally more abundant in nearshore areas than within Grays Harbor. A general pattern of migration and populati- mixing was described, which indicates a great deal of movement to and from the Grays Harbor subtidal at certain times of the year.

Natural survival of juvenile crab was estimated from age-class abundance estimates from a Sea Grant Program data series. Little statistical confidence can be put on these estimates because the variances of the population estimates were quite high. Survival was found to vary with age of crabs. For 0+ crabs, annual survival (excluding newly settled crab in years of high abundance) was estimated to be about 3% within Grays Harbor (intertidal and subtidal combined). Survival increased with age,

reaching 23% to 45% (by two different estimation techniques) for age 2+ crabs. Estimates for older crabs were not reliable.

S3. DREDGE ENTRAINMENT STUDIES

A variety of Dungeness crab entrainment studies have been conducted in the last 10 years. Few of these have provided data useful in relating dredge entrainment to crab abundance, a relationship which is essential to our model. Recent studies in Grays Harbor, conducted jointly by the Army Corps of Engineers and the University of Washington School of Fisheries, have provided the most useful data. Crab entrainment rates for hopper dredges have been reported to range widely: from 0.046 to 0.587 crab/cy of dredged material in Grays Harbor, and up to 11.0 crab/cy in the Columbia River.

Mortality of entrained crabs has received little study, but is thought to depend on dredge type, disposal methodology, crab size, and crab shell condition. For hopper dredges, a size-dependent mortality schedule was adopted, with rates ranging from 5% of those entrained for newly settled crab to 80% for large crab. For pipeline dredges with confined disposal, mortality was presumed to be 100%. For clamshell dredges, 10% mortality was used for all crab sizes.

S4. DESIGN OF THE MODEL AND ASSUMPTIONS

A model of the entrainment process was developed that applies projected dredging schedules to crab abundances estimated in different areas of Grays Harbor in different seasons of the year. Central to this model is an entrainment function that predicts entrainment rate (crab per volume dredged) from estimates of local crab density. We used two forms of this function, one linear and one curvilinear, because current understanding of the entrainment process is insufficient to choose between these forms. The curvilinear function provides a better fit to the scarce

data, but the linear function is more reliable (loss biased) in relation to the structure of our model and the nature of the population data used.

Applying these functions to observed crab densities, and multiplying the result by the volume of material dredged in any locality and season, we calculated the number of crabs entrained. These numbers were then apportioned among the age classes present. The entrainment mortality schedule was then applied separately to crabs entrained in each age class to calculate the number of crabs lost. In order to compare losses from the various age classes on an equal basis, they were converted to numbers equivalent to age 2+ crab. These numbers were then summed for dredging in all channel reaches and all seasons of the construction to estimate total project crab losses.

These calculations rely on a great number of assumptions that are, at present, untestable. The principal assumptions that need to be considered in interpreting results are: 1) trawl efficiency was assumed to be 100% for all age classes in all seasons; 2) local crab density was constant during any season because crab were assumed to move immediately into the channels to replace crab entrained; 3) crab densities in the navigation channel were assumed to be equal to those estimated for the surrounding subtidal areas; and 4) our rate estimates were assumed accurate. However, we cannot, at present, evaluate the net effect of these assumptions on loss predictions.

S5. CALCULATION OF ENTRAINMENT AND LOSS

Entrainment and loss of crabs were calculated for two dredging scenarios (plans <u>with</u> and <u>without</u> confined disposal), three population scenarios ("mean", "best", and "worst") chosen to demonstrate the most

probable range of dredging impacts, and two entrainment functions (linear and curved).

First, a set of loss rate (crabs killed per volume dredged) calculations was made for the "mean" population to provide a comparison of different dredge types in different seasons in two sections of the Grays Harbor subtidal. These calculations show that the pipeline dredge has the greatest impact and the clamshell the least impact. There is also a great deal of variation in loss rate by season and location. Considering only 1+ and older crab, June to September is the worst season to dredge in the Outer Harbor (Bar Reach to South Reach). For the Inner Harbor (Crossover Reach to Aberdeen Reach), the worst season is April and May. This information, in combination with other considerations, may be useful for further refining the dredging schedule to mitigate crab loss.

Second, losses were projected for the two proposed dredging plans. For the plan <u>without</u> confined disposal, total project loss estimates ranged from 108,000 to 576,000 crabs on an age 2+ equivalent basis. These losses resulted primarily from entrainment of 1+ and older crabs during the second project year. The largest single-reach losses resulted from dredging the outer bar during the summer season. For the plan <u>with</u> confined disposal, loss projections ranged from 116,000 to 778,000 age 2+ equivalent crabs. Again, these losses were primarily from older crabs during the second project year, and the outer bar dredging caused the largest single-reach loss.

Calculations were also made for the confined disposal plan assuming that the pipeline dredge entrainment rate was only 33% of the hopper rate. This change brought total loss projections for that plan down to a level close to that for the plan without confined disposal.

S6. POTENTIAL LOSS TO THE FISHERY

The step of taking estimated losses of male and female juvenile crab and projecting them to loss of males from a future fishery is tenuous, and is predicated on assumptions about natural and fishery mortality of adults. We have little real basis for these assumptions, so the reader should be cautious in interpreting these projections. Two methods were used for these projections.

First, loss at age 2+ was projected forward to predict loss to the age 3+ male population, which should be just recruiting to the fishery. We did this for the "mean" population scenario and the linear entrainment function. We assumed a 1:1 sex ratio and 45% survival from age 2+ to 3+. For the plan <u>without</u> confined disposal, total project loss would be about 38,000 age 3+ males. For the plan <u>with</u> confined disposal, this number would be about 45,400. These losses will not all be seen in a single year, but will be distributed over four years following construction, as the various year classes subjected to dredging recruit to the fishery. The bulk of loss to the fishery will occur two years after construction ends.

Second, losses were compared to historical Washington coast crab landings. The highest and lowest losses predicted by the entrainment model were converted to an estimate of loss to the crab catch, and this result was compared to the highest and lowest recent coastwide annual crab landings. The predicted losses (if they all occurred during a single fishing season) would represent anywhere from 0.7% to 6.4% of Washington coastwide landings for the plan <u>without</u> confined disposal, or from 0.7% to 8.6% for the plan <u>with</u> confined disposal.

S7. RECOMMENDATIONS FOR FURTHER STUDY

Several of the problems associated with this model could be resolved. Suggested approaches include: refinement of the entrainment - versus -

crab abundance relationship, analysis of sex ratios in the Sea Grant crab survey data, and improved natural mortality estimates. For accurate assessment of actual project impacts, monitoring during construction is essential. This work could be extended to estimate losses during future channel maintenance.

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Phillips-Meade, and Jenni Hewes for their efforts in typing and revising the text and tables. We thank all others of the Grays Harbor Coastal Crab Research Team, especially Donald Gunderson, Robert McConnaughey, Brandt Gutermuth, M.C. Howie, Laurie Bernstein, and Yun Bing Shi, for their dedication in both the field and laboratory. This report will also be issued by the University of Washington as Fisheries Research Institute Report FRI-UW-8702.

1.0 INTRODUCTION

The effects of dredging on marine organisms as well as subsequent changes in sediment composition and hydrography have been an issue of environmental concern for several decades. Most studies that deal with the impact of dredging and disposal of dredged material are concerned with changes in invertebrate species assemblages and community characteristics, and generally measure effects by pre- and postdredging comparisons. Predictive models of impact have not been developed for these animal groups; instead, investigators tend to imagine the sorts of community change that might occur on the basis of alterations in sediment composition, current patterns and flow rates. Very little work has been done on the entrainment and extent of damage to populations of mobile epibenthic invertebrates or demersal fish, in part because such species are difficult to quantify in a before/after comparison for a particular dredging operation. A brief review of the literature will give some perspective of the types of studies conducted to date and the animal groups on which they focus.

1.1 Studies of Dredging Impact on Infauna

Most easily documented have been changes in species composition, diversity, and richness of infaunal marine invertebrates before and after dredging in particular areas. A rather thorough review of such work was provided by Poiner and Kennedy (1984), who studied changes in the macrobenthos of a large sandbank following dredging in Moreton Bay, Queensland, Australia. They found significant decreases in species richness (the number of species per sampling site), total abundance of animals per sampling site, and species diversity following dredging. A similar change in an infaunal community had been previously found in the

Pacific Northwest by Swartz et al. (1980), who documented the effects of a dredging operation in Yaquina Bay, Oregon, and found a 52% decline in species richness as well as a 20% decline in density of organisms compared to pre-dredging baseline values. Kaplan et al. (1975) reported similar changes in community composition, as well as recolonization of a dredged channel on Long Island, New York.

In addition to immediate changes in species composition and community structure, many studies have noted that it can take a long time for recolonization and recovery to occur. Both Kaplan et al. (1975) and Swartz et al. (1980) reported that infaunal communities had not recovered to predredging conditions almost a year after dredging. On the other hand, McCauley et al. (1977) found that infauna returned to predisturbance levels within 28 days after maintenance dredging in Coos Bay, Oregon. Swartz et al. speculated that the rate of recovery is dependent on the degree of complexity of the original community and that recovery time increases with complexity.

Importance of infaunal community information in the context of Dungeness crab (Cancer magister) impact is most likely related to food type, availability, and quantity. However, in the calculations that follow, we do not consider effects on crab through food loss or habitat alteration. Such calculations would be extremely unrealistic because we do not presently have any concept of the limitations imposed on the estuarine populations by any sort of intrinsic carrying capacity. However, an approximation might be possible on the basis of the crab feeding data of Stevens et al. (1982) and infaunal data from Albright and Borithilette (1982).

In addition to effects in dredged areas per se, other studies have focused on animal colonization and use of dredged materials in disposal

areas. In the same study in which Poiner and Kennedy (1984) documented tremendous reduction of species within the area dredged, they also reported enhancement (in terms of both species richness and total abundance) in areas adjacent to the dredge site that correspond to sediment newly deposited by the dredge plume during operations. They suggested that such an enhancement for infaunal species is probably a response of benthic biota to increased available resources, an idea shared by Rhoads et al. (1978) and Swartz et al. (1980), particularly in regard to opportunistic colonizing species. Kaplan et al. (1975) observed that the crab Neopanope texana was one of the first species to colonize dredged areas in a small Long Island (New York) lagoon, probably in response to different types of readily available prey. In one of the few studies of direct impact of dredged material disposal on an epibenthic species, Elner and Hamet (1984) reported a significant loss of juvenile lobster (Homarus americanus) habitat (rock and cobble) in Halifax Harbour, Nova Scotia, following coverage by noncontaminated sands, silts, and clay. However, there is not a close parallel between the lobster study and Dungeness crab in the Grays Harbor area, as the principal habitat of Dungeness crab is relatively open sand rather than the rock and cobble typical of Homarus lobster.

In general, few attempts have been made to develop predictive models of dredging impacts on marine invertebrates and the physical system, although a model developed by Bella and Williamson (1980) was applied to dredging activities in Coos Bay, Oregon. Most variables in that model pertained to water chemistry and sediments, but some attention was given to generalized categories of animals such as benthic burrowers, indicator species, and predators. In an interesting approach to crustacean enhancement and the need for confined disposal of pipeline-dredged

materials, Quick et al. (1978) studied the feasibility of shrimp mariculture in containment areas, and documented relatively good success with this approach although the financial feasibility was less clear.

1.2 Studies of Dredging Impact on Dungeness Crab

Most attention regarding the impact of dredging operations on Dungeness crab has been focused within estuaries rather than in nearshore coastal areas because estuaries are perceived to be important to juvenile crab (see reviews by Stevens and Armstrong 1984; Armstrong and Gunderson 1985). A program was initiated by the Army Corps of Engineers (COE) in the mid-1970s to determine the potential impact of dredging in Grays Harbor on a variety of animal groups including Dungeness crab. The first directed study of crab entrainment by a hopper dredge was performed by Tegelberg and Arthur (1977), who obtained questionable results because of sampling difficulties with both hopper and pipeline dredge effluents.

Sampling methodology for estimation of dredge entrainment and mortality of Dungeness crab was described by Stevens (1981), who sampled clamshell, hopper, and pipeline dredges in Grays Harbor. He measured entrainment as number of crabs per cubic yard (cy). This work led to further studies of entrainment and measures of crab density and population abundance throughout the estuary (Armstrong et al. 1982; Stevens and Armstrong 1984, 1985). Although these studies provided valuable information, their disadvantage (in terms of impact assessment) was that estimates of dredge entrainment of crab were not coupled with estimates of crab density or population abundance. In order to gain more exact information on the rate of crab entrainment relative to density, COE conducted a series of studies with modified sampling gear in October 1985 and August 1986 (McGraw et al. 1987), accompanied by surveys of benthic crab density and abundance (Dinnel et al. 1986a,b). The information from

these combined studies became an integral part of the present crab impact calculation, providing a means to relate the number of crabs entrained per unit of material dredged with the density of crab present. Dungeness crab entrainment and impact have also been recently studied in the Columbia River estuary by the Portland District COE and the National Marine Fisheries Service. Their program has particularly addressed the intensity of entrainment of newly settled young-of-the-year (0+ age class) crab on the Columbia River Bar and just inside the estuary (C.O.E. 1986). Entrainment rates for Dungeness crab calculated in that program were the highest reported to date, and reflect the small size and high vulnerability of newly settled crab to hopper dredge operations. Further measures of pipeline entrainment mortality of Dungeness crab were presented by Archibald (1983) during a study of dredging operations on the Roberts Bank Superport expansion in British Columbia.

1.3 Intent of the Model

For any dredging program, in particular the proposed widening and deepening (W&D) operation in Grays Harbor, a substantial amount of information is available from which to numerically estimate the potential impact on Dungeness crab in terms of both animals entrained and animals subsequently killed. The first attempts at these sorts of calculations, made by Stevens (1981) and Armstrong et al. (1982) in Grays Harbor, demonstrated the utility of such estimates as a means to assess whether the potential loss to the population, as well as to the commercial fishery, is or is not significant.

Using the sort of dredge information detailed in Sections 2.2, 3.0, and 4.0, our first intention in this model is to predict the number of crab in three age classes (0+, 1+, >1+) entrained and killed during the two-year

dredging schedule proposed by COE to widen and deepen Grays Harbor. This schedule includes several variables: 1) the type of dredge gear to be used; 2) the areas (reaches) of the navigation channel where the gear is to be used; 3) the volume of material to be dredged from each reach; and 4) the scheduling (by season) of the various gear types in specific reaches. Crab biology is considered relative to the seasonal geographic distributions of the age classes and to patterns of movement and settlement in the estuary and the nearshore coastal area. The intended result is an estimate of number of crabs entrained and killed by dredging as a function of gear type and size category of crab, and the relationship of those numbers to the estuarine and nearshore crab population as a whole. The immediate utility of these types of estimates is to enable scrutiny of initial dredging schedules, which may then be modified to minimize predicted impacts of W&D on the crab resource. Indeed, COE has already used preliminary results from this study in designing the current dredging plan.

The second intent of the model is to use those estimates to forecast what this loss will mean to the future commercial crab fishery. The results of previous calculations and of this model have been used by the Crab Study Panel in several ways: 1) primarily to recommend changes in the dredge scheduling program; 2) to call for modifications to dredge equipment itself; 3) to consider the type and amount of mitigation necessary in view of estimated crabs lost as predicted by the model; and 4) finally, as a possible means to calculate compensation for future fishery loss if the impact is judged to be significant.

2.0 SOURCES AND USE OF DATA

2.1 General Crab Biology and Ecology

The literature on Dungeness crab, which dates from 1930, is extensive and covers a wide variety of topics. Most of the literature is not pertinent to the present work, but readers may wish to refer to the many articles in a special Alaska Sea Grant Symposium (Alaska Sea Grant 1985) that outline the history of the fisheries as well as general ecology and biology of this species (also see Wild and Tasto 1983). The biological information most essential for predicting impacts of dredging includes: local population structure (age composition, spatial distribution, and seasonal movements), growth and the relationship between size and age, natural mortality rates, and fishery catch information. Extensive reviews pertaining primarily to population dynamics in Grays Harbor and along the southern Washington coast have been provided by Stevens and Armstrong (1984; 1985); Armstrong and Gunderson (1985); and Armstrong et al. (1984, 1985, 1986).

2.1.1 Life History

Dungeness crabs are found nearshore along the open coast and in estuaries from central California through southeastern Alaska (see Alaska Sea Grant 1985). Mature crab and all reproductive events occur along the open coast and, with the exception of Puget Sound, there is no evidence of reproductive activities in coastal estuaries including San Francisco and Humboldt Bays, California, and Grays Harbor, Washington (Tasto 1983; Stevens and Armstrong 1984, 1985; Armstrong and Gunderson 1985). A general life history scenario (Fig. 2.1) indicates that females molt to maturity nearshore, generally in the spring; they are bred there by males, carry sperm for about six months, and extrude an egg mass the following fall.

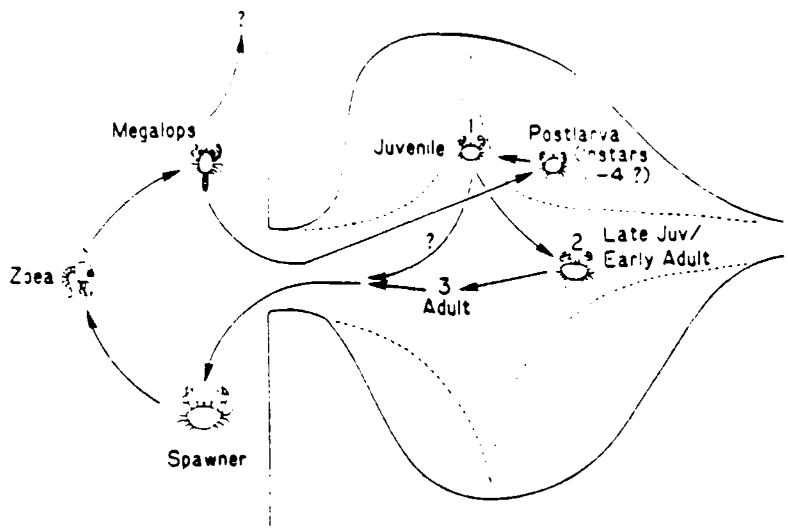


Figure 2.1. General hypothesis for early life history of Cancer magister in estuaries. Numbers indicate predominant location of age groups. Many probably leave the estuary after one year. All spawning is oceanic.

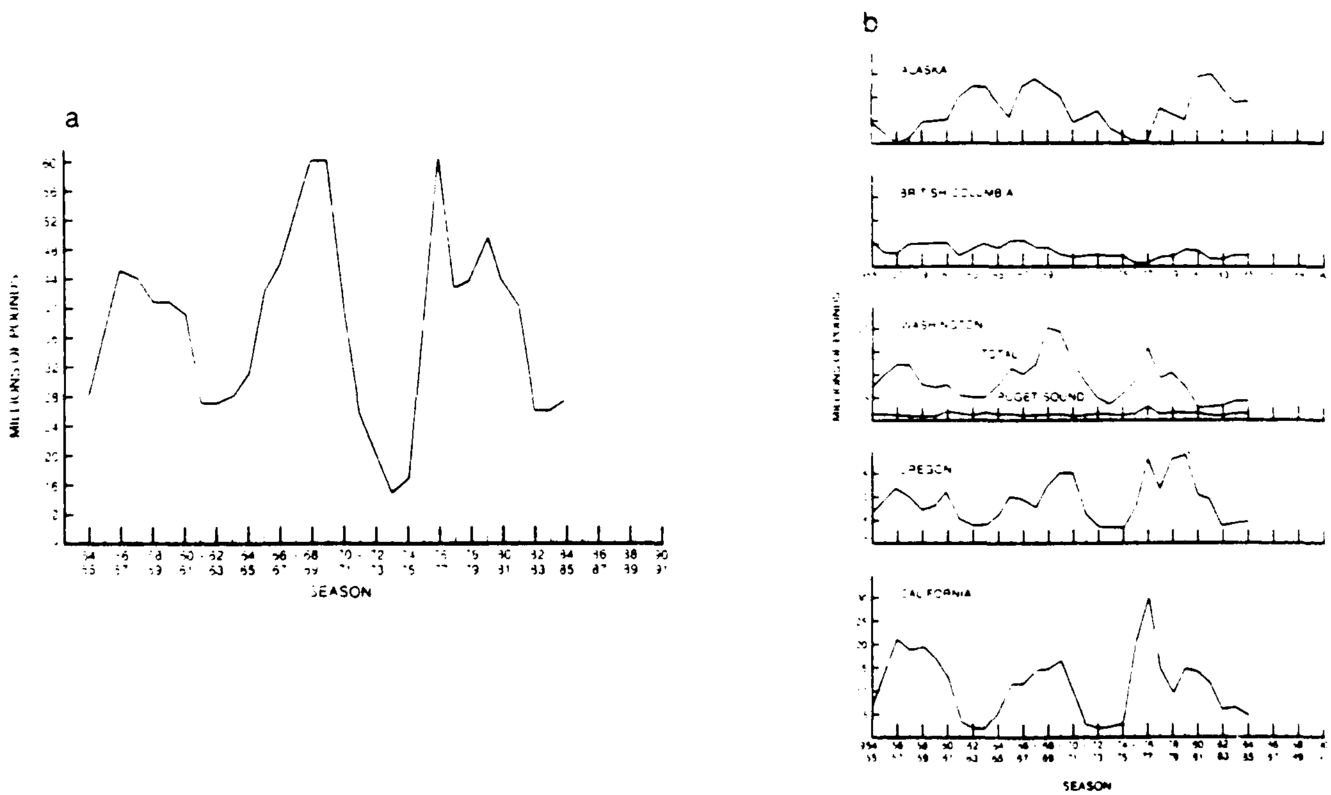


Figure 2.2. Pacific Coast Dungeness crab landings by season, 1954-1985. a: coastwide total; b: by jurisdiction.

This egg mass is carried on the abdomen of the female for approximately 3 months. Larvae hatch in the winter primarily between December and February, and progress through five larval stages, called zoeae, which occur in the water column between December and March. There is evidence that larvae are carried progressively farther offshore through the five developmental stages (Lough 1976; Reilly 1983), and it is speculated that larvae might also be transported substantial distances alongshore during this period, particularly from south to north in the Davidson current (Reilly 1983; Johnson et al. 1986). After the five zoeal stages, larvae molt one last time to the final pelagic stage, called a megalopa. Megalopae return onshore during late spring and summer by directed swimming and/or in favorable current regimes (Lough 1976; Reilly 1983; Johnson et al. 1986).

Movement of megalopae onshore is among the factors critical for successful year-class strength. Megalopae are most prevalent within a few kilometers of shoreline where they settle to the bottom and metamorphose into first-instar benthic juveniles (Fig. 2.1; Armstrong and Gunderson 1985; Stevens and Armstrong 1985). Movement onshore may be regulated by chemosensory behavior and detection of lower salinity nearshore plumes associated with estuaries (Sugarman et al. 1983), and indeed, megalopae directly enter the Grays Harbor estuary in high abundances (Stevens and Armstrong 1984; Armstrong and Gunderson 1985; Armstrong et al. 1985). After settlement and metamorphosis, growth of juvenile crab in estuaries (Tasto 1983; Stevens and Armstrong 1984; Armstrong and Gunderson 1985) is substantially faster than nearshore (Butler 1961; Poole 1967; Tasto 1983; Armstrong and Gunderson 1985), which further underscores the importance of transport/movement onshore and entry into estuaries. Both male and female crab reach sexual maturity at about 2 years of age (Butler 1961; Hankin et

al. 1985), although males may not breed until age 3 years or older. Late juvenile and early adult crab leave coastal estuaries before reproduction, which occurs along the coast, thus completing the life cycle (Fig. 2.1).

2.1.2 The Fishery

The bulk of the fishery for Dungeness crab is located nearshore in relatively shallow water less than 50 m depth where only males >160 mm carapace width (CW) are taken in pots in most jurisdictions. The coastal fisheries generally open in December and most of annual landings occur by March (see series of reviews in Alaska Sea Grant 1985). Apparent cycles of abundance, showing a period of about 9 to 10 years, are a striking feature of the series of annual landings of Dungeness crab along the coast from California through Washington (Fig. 2.2; Pacific Marine Fisheries Commission 1985; Botsford 1986). Methot and Botsford (1982) estimated preseason abundance of male Dungeness crab from actual fisheries data and determined that the time series of population abundance and recruitment is not as smoothly cyclical as is the catch record, and that the fishery can occasionally be dominated by single exceedingly strong year classes. Indeed, such a catch record may be highly imperfect as an indicator of actual population abundance for various age classes, but it does highlight the great success of Dungeness crab recruitment along the coast in some years, probably for reasons related to nearshore oceanographic features and processes. Year classes that have been apparently strong or weak have occurred inside and nearshore of Grays Harbor between 1983 and 1986; those are described in Section 2.3. Knowledge of such extreme variability is important in evaluating resource impacts: estimates from one year's data are not directly applicable to another year. In our calculations of

dredging impact, we have addressed this problem by providing estimates for "best" and "worst" crab populations, as described in Section 4.0.

2.2 Size-at-Age and Growth

2.2.1 Introduction

To understand the dynamics of a fishery and, in particular, the consequences of removing a certain number of individuals from the population, we need information about the age structure of the population and about individual growth and mortality rates. For most fish species, age can be estimated from marks in hard structures (such as scales or otoliths). Crabs retain no indications of age in their hard parts, so we are forced to estimate age from size measurements. Age classes of fish (and some shellfish) have been successfully identified from peaks (or "modes") in the distribution of sizes in samples from the population. This technique is called modal analysis or size-frequency analysis, and has been reviewed recently by Schnute and Fournier (1980).

This method, however, is difficult to apply to crabs and other crustaceans because they grow by molting. As a result, each age group is usually composed of several "modal groups", one corresponding to each instar (molt stage) representing each molting episode. This contrasts with the usual case in fishes, in which each age group is composed of a single "modal group" (Fig. 2.3). Thus, the analysis for crab leads to the decomposition of the size-frequency distribution (SFD) into instar groups, rather than year classes. In order to assign instars to age groups, it is necessary to have additional information on molting frequency, which can be obtained from field samples of molt-casts, from lab experiments, or, as in this study, from periodic sampling of the population.

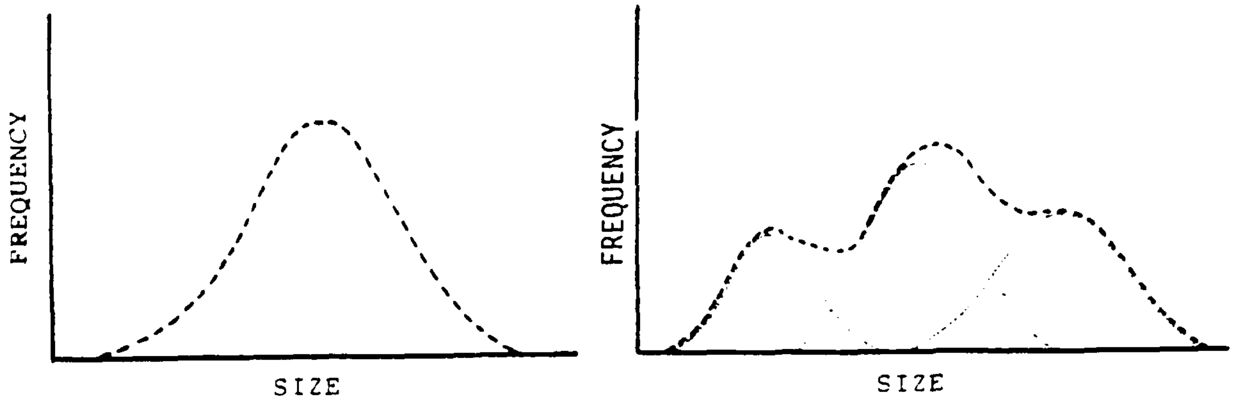


Figure 2.3. Schematic representation of the size-frequency distribution of a single year class of a fish (left) and a crab (right).

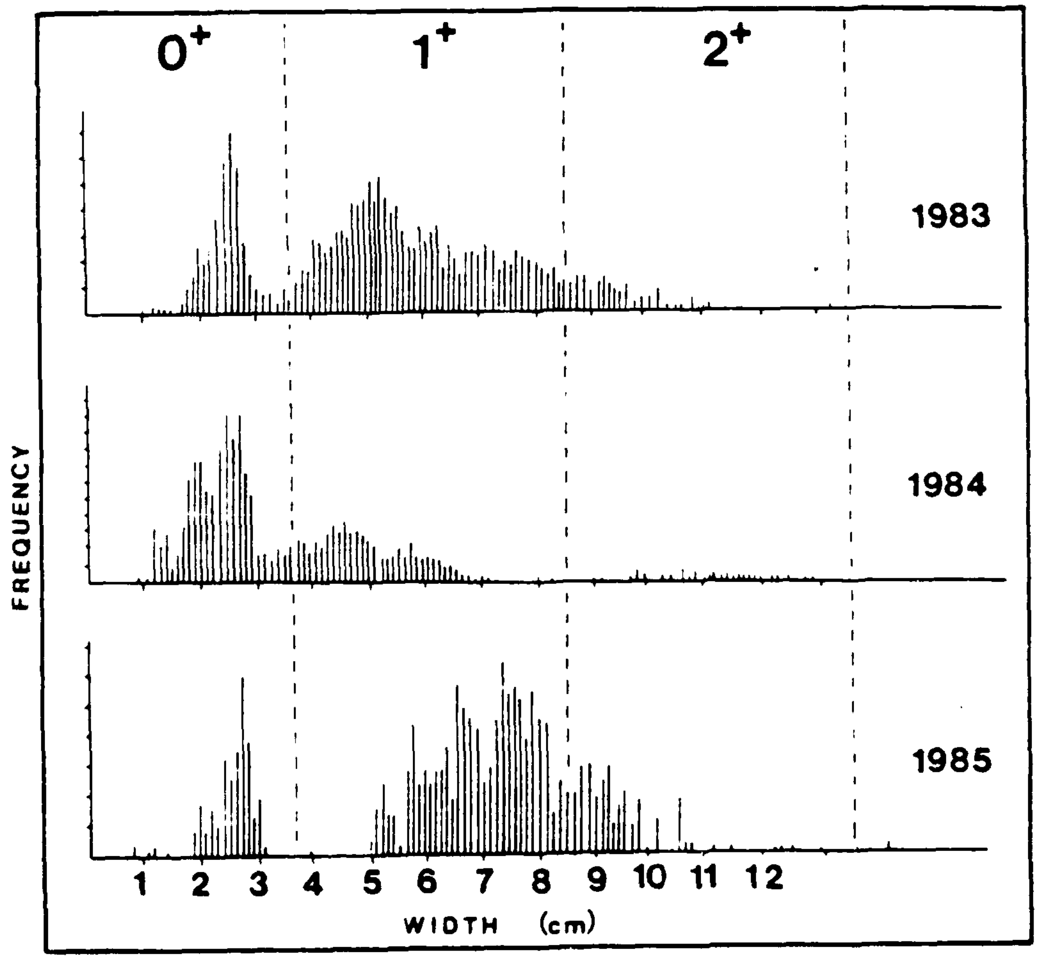


Figure 2.4. Size-frequency distributions of Dungeness crab from Grays Harbor in the month of July, 1983-1985. Notice year-to-year variation in mean size and spread of the 1+ group, as compared with visually determined fixed boundaries (vertical bars).

In summary, the study of crustacean growth patterns involves the estimation of two separate components: size-at-instar schedules and instar-at-age schedules. Both components are sex specific, at least for mature animals. Growth patterns can be affected by the genetic makeup of the individuals and by the environment (e.g., temperature, salinity, food availability), and for that reason they are expected to show geographic and seasonal variation. All these sources of variation, together with mixing of populations resulting from migratory displacements, tend to blur patterns in the SFDs and often discourage their analysis.

Previous studies of Dungeness crab populations made use of visually determined size boundaries to separate age classes (e.g., Stevens and Armstrong 1984). The method works well to segregate the first age group (0+) but has obvious limitations for older animals. Figure 2.4 illustrates some of these:

1. The overlap between adjacent year classes is disregarded;
2. Year-to-year variation in the spread of a given year class (see the 1+ group, for example) is not accounted for; and
3. The information contained in the intrayear class SFD is not utilized.

To overcome all these difficulties, and to make full use of the information available, this study applied numerical methods to analyze SFD data. This approach is described in Section 2.2.2, and results are given in Sections 2.2.3 to 2.2.5.

2.2.2 Analysis of Size-Frequency Distributions (SFD)

The basic information available is composed of SFDs obtained during the regular Sea Grant surveys done in 1983-1986 in Grays Harbor (called

"estuary" here) and the adjacent coastal area ("nearshore"). Data were pooled in the following ways:

1. Sexes were pooled for specimens smaller than 30 mm carapace width (CW). For larger crabs, sexes were analyzed separately.
2. All the stations were pooled within each of the two areas (estuary and nearshore) because the data for a single station were in most cases insufficient for analytical purposes.
3. Data from all the sampling cruises of each calendar year (cruises from April through October) were divided into two groups (0+ and older crabs) which did not overlap in size range. Data from all the cruises in each age group were pooled, keeping the sexes separate, to obtain growth schedules. Each cruise was analyzed separately.
4. In some cases, data for a given cohort were pooled for two consecutive years (ages 0+ and 1+) to derive more complete size-at-instar schedules.

The analytical procedure used to decompose SFDs into instar groups is similar to the methods of MacDonald and Pitcher (1979), Schnute and Fournier (1980), and Orensanz and Gallucci (unpublished data). This is a powerful procedure which can, in many circumstances, identify modes that cannot be found by visual inspection. The approach assumes that the size distribution of the populaton represents the sum of a series of approximately normal (Gaussian) distributions, each corresponding to the size distribution of a single instar. Numerical minimization methods are used to find the series of normal curves that best fit the sample SFD. The procedure is made faster and simpler by further assuming that the standard deviation of size for any instar is linearly related to its mean size. Both this assumption and that of normality of the instar size distributions

have been empirically supported elsewhere (Botsford 1984; Orensanz and Gallucci, unpublished data). A complete description of these methods is beyond the scope of this report. Readers who wish details of the methods used are referred to the works cited.

The final result of this calculation is, for each instar in the sample, estimates of three values:

1. Mean size of the instar;
2. Standard deviation of size for the instar; and
3. The proportion of the total population represented by that instar.

2.2.3 Growth Schedules

Size-at-instar schedules were estimated for all the years of study and also for data collected in 1980-1981 in Grays Harbor as part of an earlier study (Stevens and Armstrong 1984). The following sources of variation were explored:

1. Differences between sexes,
2. Differences between the estuary and nearshore areas, and
3. Differences between year classes within each area.

The following notation will be used in the following discussion:

Instars whose average size is below 100 mm CW will be labeled "J1, J2, ... etc." (J = juvenile). The largest J instar will be labeled "J+".

Instars whose average size is above 100 mm CW will be labeled "A1, A2, ... etc." (A = adult).

It has been observed in previous studies that crabs from the estuary grow faster than those from nearshore areas (Carrasco et al. 1985). Cleaver (1949) estimated that crabs from the estuary go through 11 juvenile instars. This study confirms both results, and yields additional insights on growth patterns discussed below.

Size-at-instar for juveniles: Juvenile crabs from the estuary molt more often than those nearshore, but size increments per molt are larger for the nearshore crabs. As a result, nearshore crab pass through 10 (as opposed to 11 within the estuary) juvenile instars to reach 100 mm CW.

The nearshore-to-estuary contrast was best seen in the 1984 year class, which was well represented in both areas. Estimated mean size-at-instar schedules are as follows :

Table 2.1 Estimated mean size-at-instar of Dungeness crab in Grays Harbor estuary and nearshore along the coast. Mean carapace width (mm) for juvenile stages 1 through 11 are given along with comparative data from Cleaver (1949).

	J1	J2	J3	J4	J5	J6	J7	J8	J9	J10	J11
Nearshore	7.3	10.9	15.3	20.0	25.9	32.3	40.0	52.5	55.8	84.2	
Estuary	7.2	10.1	14.0	19.8	25.1	30.9	37.1	46.0	56.6	73.7	87.8
Cleaver	5-7	9.0	12.0	16.0	22.4	28.8	35.2	44.6	56.4	68.4	84.9

Within the estuary, schedules estimated by us and by Cleaver (1949) agree fairly well, although Cleaver's sizes-at-instar are on the average 2.5 mm smaller than those found by us.

Relative growth-per-molt tends to decrease with size and there is some seasonal variation. Increments tend to be lower than expected when temperature is low. Figure 2.5 illustrates relative size increments for both areas.

Size-at-instar for adults: For crabs above 90 mm CW, the two groups (estuary and nearshore) are well mixed (see Section 2.4 below), converge in size, and become inseparable. Size-at-instar for instars J+ and A1-A3 were

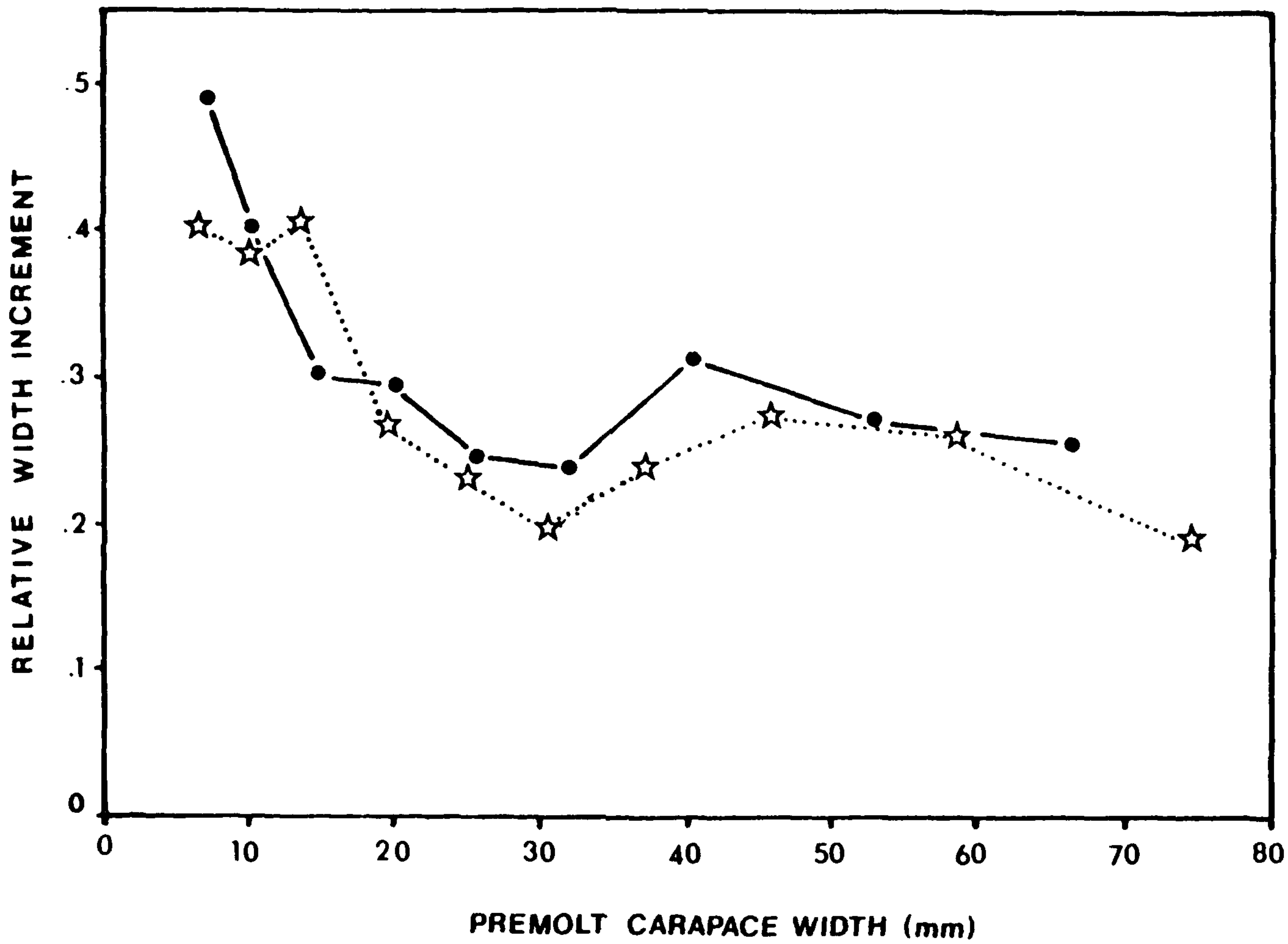


Figure 2.5. Size dependence of relative size increments per molt (expressed as a fraction of premolt size), as obtained from the numerical analysis of size-at-instar schedules. Stars, estuary; dots, nearshore.

estimated for each year and from data for all years combined. Results of the analysis are given in Table 2.2.

Table 2.2. Mean size-at-instar of Dungeness crab in Grays Harbor estuary and nearshore along the coast for the largest juvenile stage (j+) and adult instar stages A1 through A3 (size transition taken to be 100 mm CW). Data based on the four-year Sea Grant series 1983-1986. Comparative size-at-instar data from Cleaver (1949) are also given.

	Males				Females		
	J+	A1	A2	A3	J+	A1	A2
Nearshore	96.7	115.9	137.7	154.6	96.5	113.3	133.7
Estuary	92.2	110.7	137.4	151.7	90.1	103.8	125.8
Cleaver	84.9	106.4	129.1	154.4	84.9	106.4	-

The small discrepancies between our 4-year averages and Cleaver's values are generally within the range of year-to-year variation observed by us. The average size at instar A3, however, is consistently lower than expected given the observed average size at instar A2 and the results from other studies (e.g., Cleaver 1949, Table 20). A size of about 160 mm (17% size increase from A2 to A3) is probably more realistic. Two factors might account for that observation:

1. The gear utilized in our study may not be efficient for large crabs, thus biasing the estimate downward.
2. At least part of the A3 crabs in every year class are of legal (commercial) size (160 mm). The bulk of males molt from A2 to A3 during the fall, and the largest among them become available to the fishery during the winter. Fishing pressure tends to concentrate at the beginning of the fishing seasons (which opens in December). Since the surveys were always conducted between

April and September, the SFD of the males sampled A3 may reflect the selective (size-dependent) effect of the fishery.

Elucidation of this question is of great importance. Hypothesis (1) should first be critically examined. If it is substantiated, then the survey estimates of abundance should be corrected. If it is rejected, the depression of average size-at-instar A3 following the fishing season could be of great value in estimating fishing mortality. However, at this time we have no data from which to establish size selectivity of gear, so we are unable to choose between these two possibilities.

The small size-at-instar of the females from the estuary, as compared to those from nearshore, may be explained by one of the following alternative hypotheses:

1. Females emigrate when they reach sexual maturity. This and other migratory movements seem to be a size dependent movement, but movements are size dependent with larger animals within a group migrating ahead of smaller ones.

2. The difference reflects smaller size-at-instar of estuarine females. The difference between estuarine and nearshore males is blurred by movements in and out of the estuary, but females do not reenter the estuary once they emigrate after reaching maturity.

2.2.4 Growth Patterns

Figure 2.6 is a schematic representation of average growth for nearshore and estuarine males, based on the 1984 year class. It shows that intermolt periods (determined from changes in instar distributions between samples) are longer during the winter ("winter anecdysis"), and that the number of molts per year decreases with age. The pattern is very similar to that of the 1945 year class, implicit in Cleaver's (1949) Fig. 4.

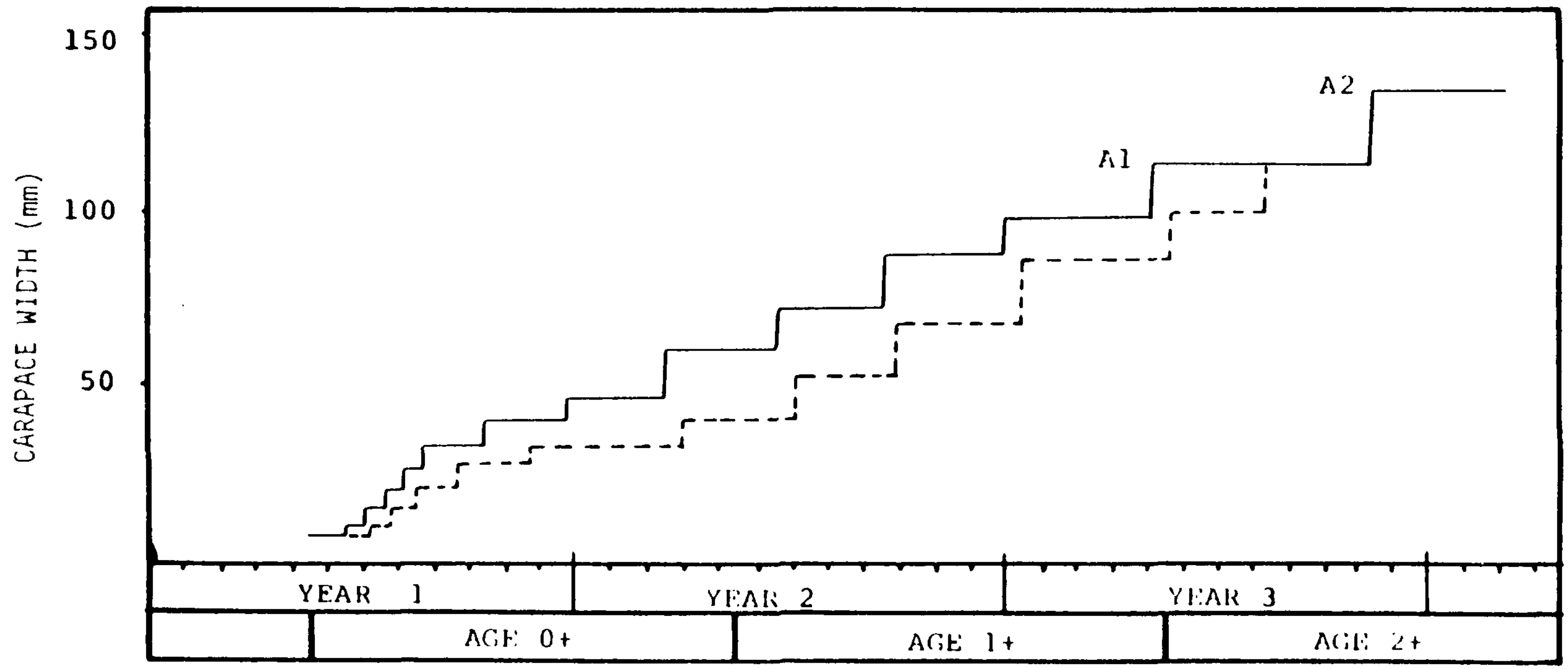


Figure 2.6. Schematic representation (based on growth of the 1984 year class) of size over ages 0+ to 2+. Solid line, estuary; dashed line, nearshore.

Growth of Grays Harbor (estuarine) crabs has been estimated by Cleaver (1949, Table 21), and depicted by Stevens and Armstrong (1984, Fig. 7) and Armstrong and Gunderson (1985) for 0+ crab. Their conclusions are schematically compared in Fig. 2.7. Inferred growth patterns are similar for the first two years of life. Cleaver's estimate was based on visual inspection for modes in SFDs of samples from 1946 and early 1947. His estimated size of 150 mm at the age of 3 years after hatching is based on the assumption that two modal groups in February 1947 (instars A2 and A3) correspond to a single age class. This is inconsistent with other pieces of evidence, including the growth pattern of the 1945 year class (implicit in Cleaver's Fig. 4).

Stevens and Armstrong's depiction was derived from the dissection of periodic SFDs by use of fixed size boundaries between age classes. Their results, based on data obtained in 1980-81, agree rather well with the schematic representation introduced in Fig. 2.6, which resulted from the application of more elaborate techniques to data gathered in 1983-1986.

Crabs tend to molt less frequently as they grow larger. Following settlement, an estuarine crab will go through, on the average, six molts during the first year, and three or four during the second year. As crabs approach maturity, molting tends to become seasonal, crabs tend to molt only once per year (older crabs may even skip molting), and male and female molting seasons tend to diverge. As adults, males tend to molt during the fall (this being the reason for the fall fishing closure), and females during the spring climax of the mating season. This study and Stevens and Armstrong's (1984) results show that the bulk of a cohort will reach instar A1 by the end of the third calendar year of life (roughly 2.5 years after settlement). After this size (110-115 mm) has been reached, males seem to molt once per year, at least until they reach instar A3. The following

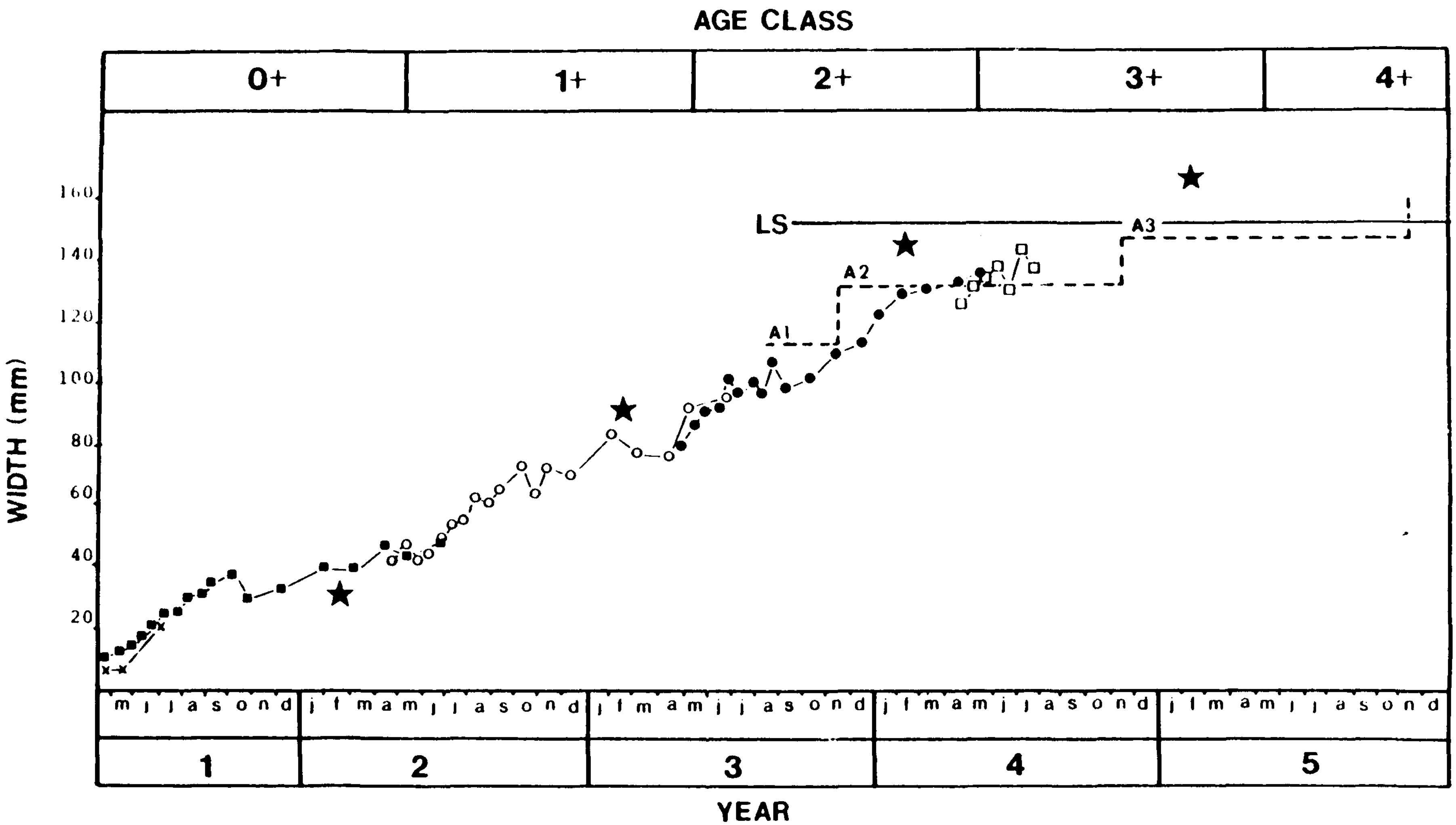


Figure 2.7. Schematic representation of growth results from different studies. Symbols connected by solid lines correspond to the 5 year classes present in the estuary in 1980-1981 (Stevens and Armstrong 1984). The dashed line tracks male growth under the assumption that the bulk of a year class molts from instar A1 to A2 at about 2.5 years of age, and from A2 to A3 at about 3.5 years of age, based on the 1983-1986 Sea Grant surveys. Stars correspond to the size-at-age schedule proposed by Cleaver (1949). LS, legal size limit.

table summarizes the average instar/age relationship for an estuary-settled male crab during its first 5 years of life:

Table 2.3. Correspondence between age and instar number for a male Dungeness crab that settles to the Grays Harbor estuary over the first five years of life. The number of juvenile and adult instars per age class category correspond to data presented in Figures 2.6 and 2.7.

Calendar year of life	Age during survey season (Apr.-Oct.)	Instars
1	0+	J1-J7
2	1+	J7-J10/11(J+)
3	2+	J1 & A1
4	3+	A2
5	4+	A3

2.2.5 Recruitment to the Fishery

Although there is much variation in growth within year classes, the bulk of a cohort seems to be rather synchronic in reaching instar A3 during the fall of the fourth calendar year of life (3.5 years after settlement). The amount of between-years variation in size-at-instar schedules is such that recruitment to the fishery of the bulk of a year class can be apportioned in a number of different ways between ages 3.5 and 4.5 years after settlement. If the average size of instar A3 is very small, one can expect: a) delayed recruitment to the fishery (at 4.5 years of age for most crabs), and b) large size of crabs in the commercial catch. Conversely, a large size at instar A3 can be expected to result in: a) an early recruitment to the fishery (about 3.5 years of age), and b) a commercial harvest composed of relatively small crabs. The last seems to have been the case for the Grays Harbor area in recent years, including the current season (Steve Barry, WDF, personal communication). There are well-

substantiated anecdotal reports of the first scenario for Washington and Oregon.

2.3 Grays Harbor and Adjacent Nearshore Population Abundance

Data on Dungeness crab populations in and near Grays Harbor come from a four-year program sponsored by Washington Sea Grant and include the years 1983 through 1986 (see Section 4.0). Much of this data has already been published in a series of articles and reports (Armstrong and Gunderson 1985; Armstrong et al. 1984, 1985, 1986) and crab abundance information from 1980-1981 has also been used when appropriate (Stevens and Armstrong 1984).

2.3.1 Estuary Subtidal

Estimates of crab population abundance are based on a standardized sampling protocol (Gunderson et al. 1985) that includes a randomized survey in the subtidal portion of Grays Harbor estuary (Fig. 2.8) at a number of stations to measure crab densities (crab/ha), which are extrapolated to total population abundance throughout the estuary. Total estimated crab abundances depicted in Figure 2.9 show high variability during the four years from 1983 through 1986. The most notable features are: 1) increase in abundance from midspring through early summer in some years (e.g., 1983, 1986), 2) high initial recruitment of young-of-the-year (0+) crab followed by rapid mortality and decline of the population in some years (e.g., 1984), and 3) an apparent decline in population abundance toward the end of summer through fall in some years (e.g., 1983, 1985, 1986). Because older, and therefore larger, crabs are a more important component of predicted loss (see Section 4.0), the population trends of 1+ crab within the estuary as well as nearshore are shown in Fig. 2.10. By comparing Figures 2.9 and 2.10, it is apparent that much of the total resident subtidal crab population in Grays Harbor during summer is composed of 1+ animals. Their

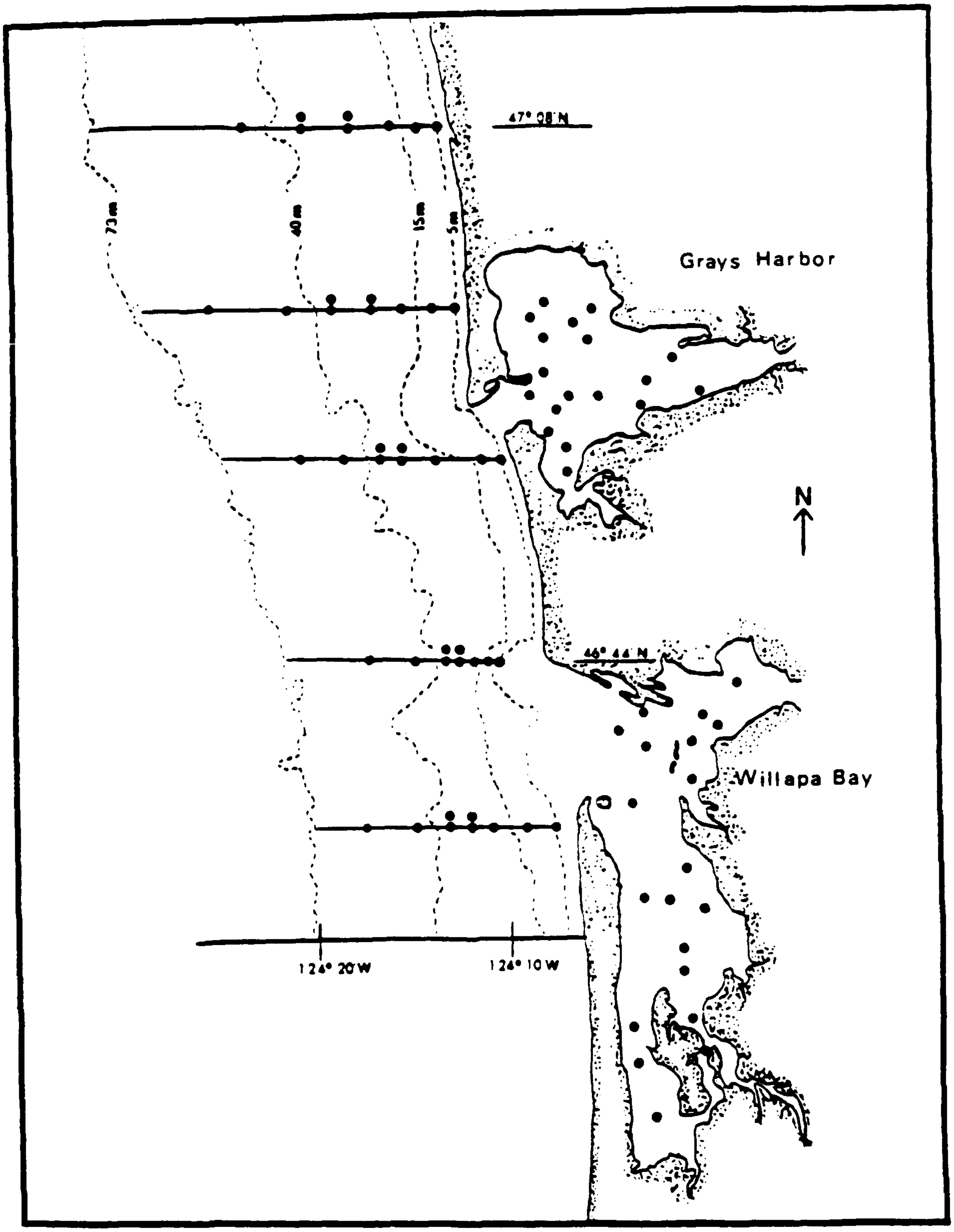


Figure 2.8. Dungeness crab survey design, Sea Grant, 1983 through 1986. Dots represent sampling stations, solid lines represent nearshore transects. Willapa Bay and two of the transects were sampled only in 1985 and 1986. Each station was sampled at least monthly from May through September.

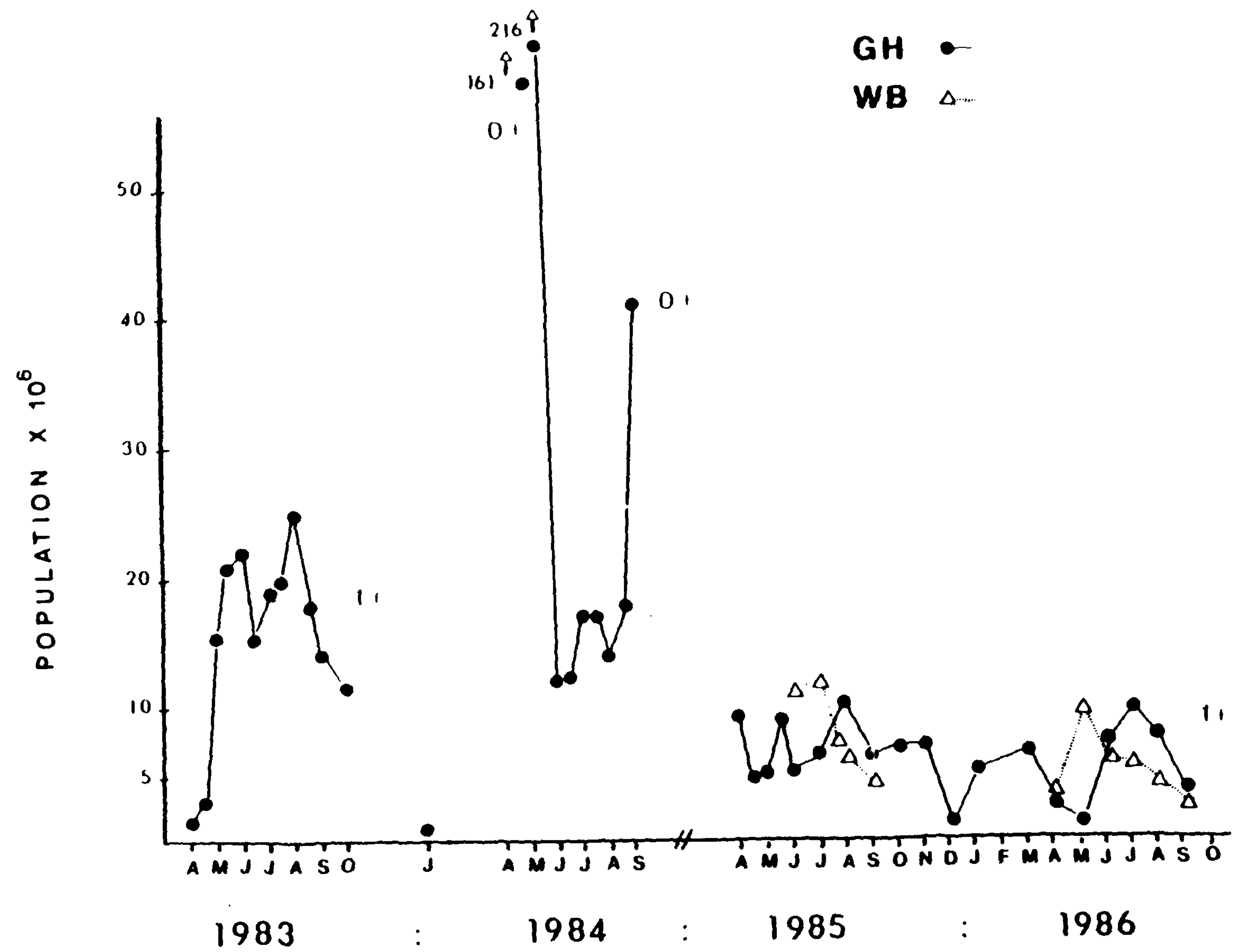


Figure 2.9. Trend in estimated total population abundance of Dungeness crab in Grays Harbor (GH) and Willapa Bay (WB). Age classes that dominate the population are shown at points throughout the years.

abundance was greatest in 1983 and generally ranged between 8 and 13 million animals, but in the summers of 1984 through 1986 it was more typically about 5 million animals (Fig. 2.10). It is also apparent that in three of the four years (the exception is 1985) the estimated population of 1+ crab within Grays Harbor was greater than that for the adjacent nearshore area, which underscores the importance of the estuary for young juvenile crab during the second summer following metamorphosis.

2.3.2 Estuary Intertidal

A very important additional portion of the estuarine population of Dungeness crab is located each summer in intertidal areas of the estuary (Fig. 2.11; Armstrong and Gunderson 1985). A program sponsored by COE and now in progress has helped to better define the location and relative abundance of crab in the intertidal, and has enabled us to calculate population abundance through the summer of the four years from 1983 through 1986. The intertidal population is composed almost entirely of 0+ crab that settle there directly from the megalopal stage and apparently survive in high densities within certain types of benthic refuge, notably empty bivalve shells. Sampling since 1983 has shown that settlement and relative year-class strength can be quite variable and are initially very high in the intertidal (Fig. 2.12).

In May, when 0+ crab settle to the benthos, density can range from 3 to $300/m^2$, but mortality is rapid and, on average, the summer population is more typically between 10 to $20/m^2$ (Fig. 2.12). Surveys of shell habitat on the intertidal areas of Grays Harbor have provided estimates of the total hectares of shell as well as net cover when corrected for open space in areas of general cover (Fig. 2.11). By extrapolating numbers of crab per square meter of shell (Fig. 2.11) to the total area of such habitat

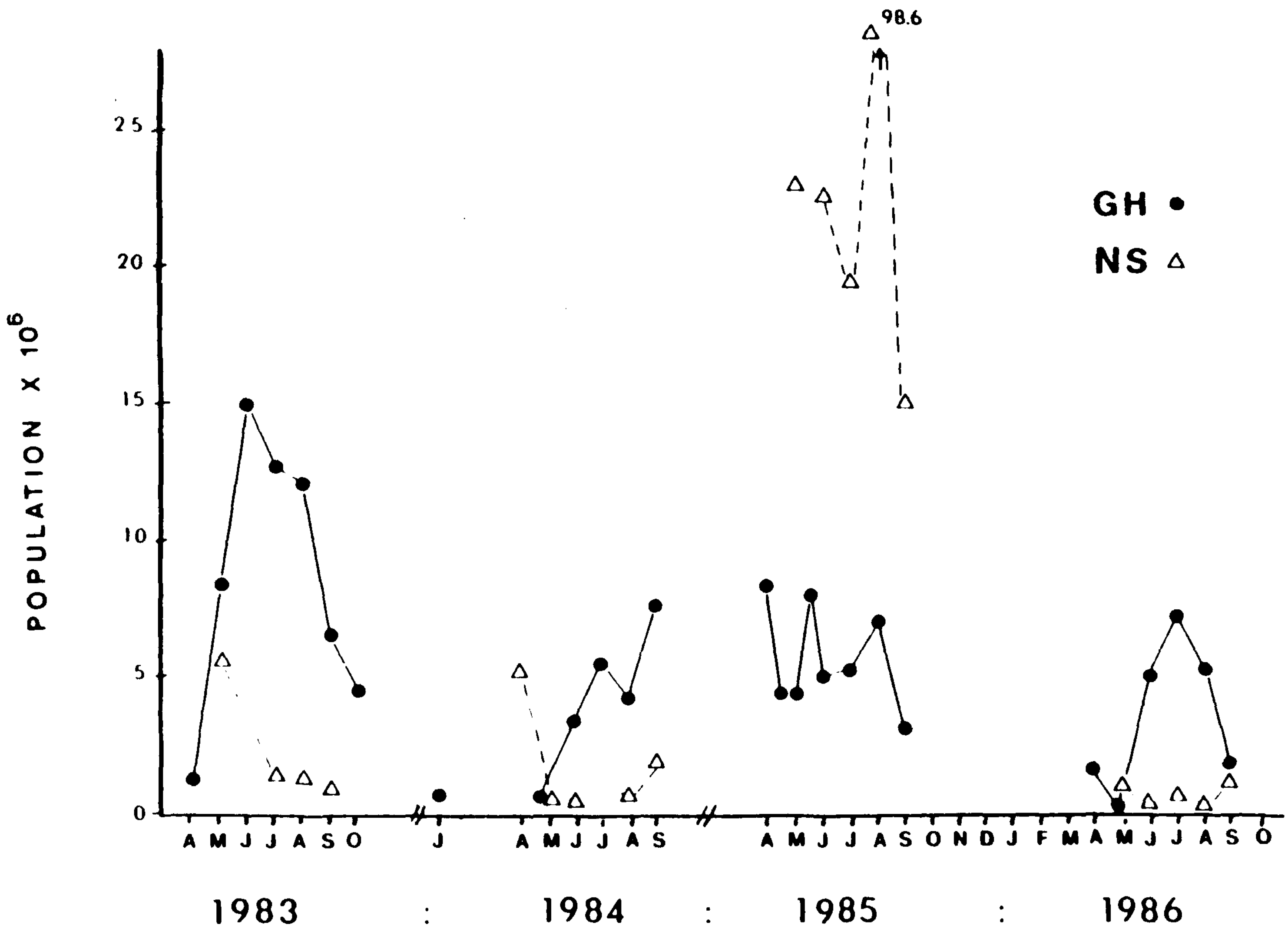


Figure 2.10. Estimated population abundance of 1+ Dungeness crab in Grays Harbor estuary (GH) and nearshore (NS). Note that in three of the four years abundance was greater inside Grays Harbor.

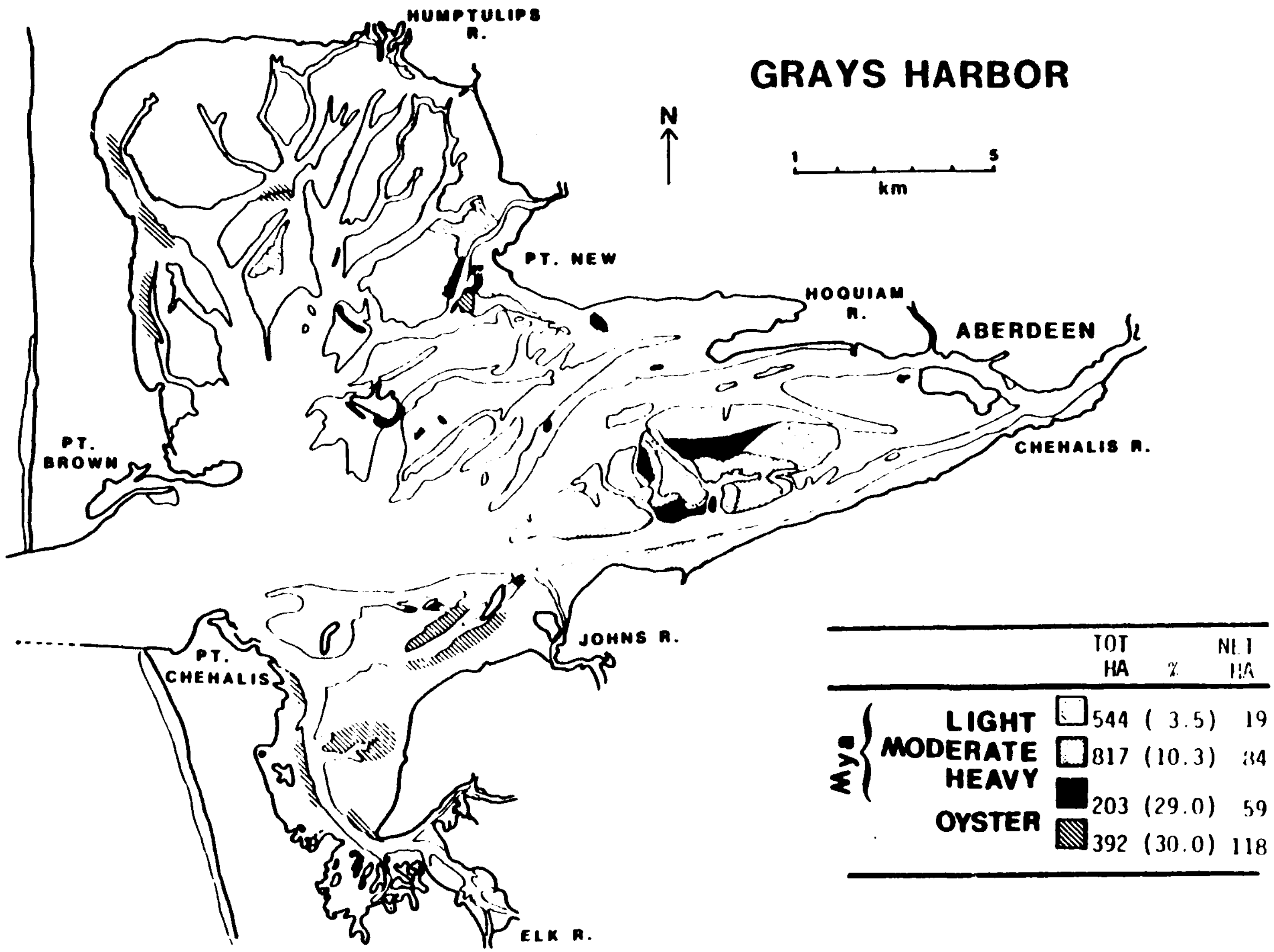


Figure 2.11. Intertidal area of Grays Harbor (outline) and major shell deposits (shaded) throughout as determined from helicopter and groundtruthing. Shown are coverage of shell in several categories, a percentage correction to account for actual coverage within general areas, and net coverage of solid shell.

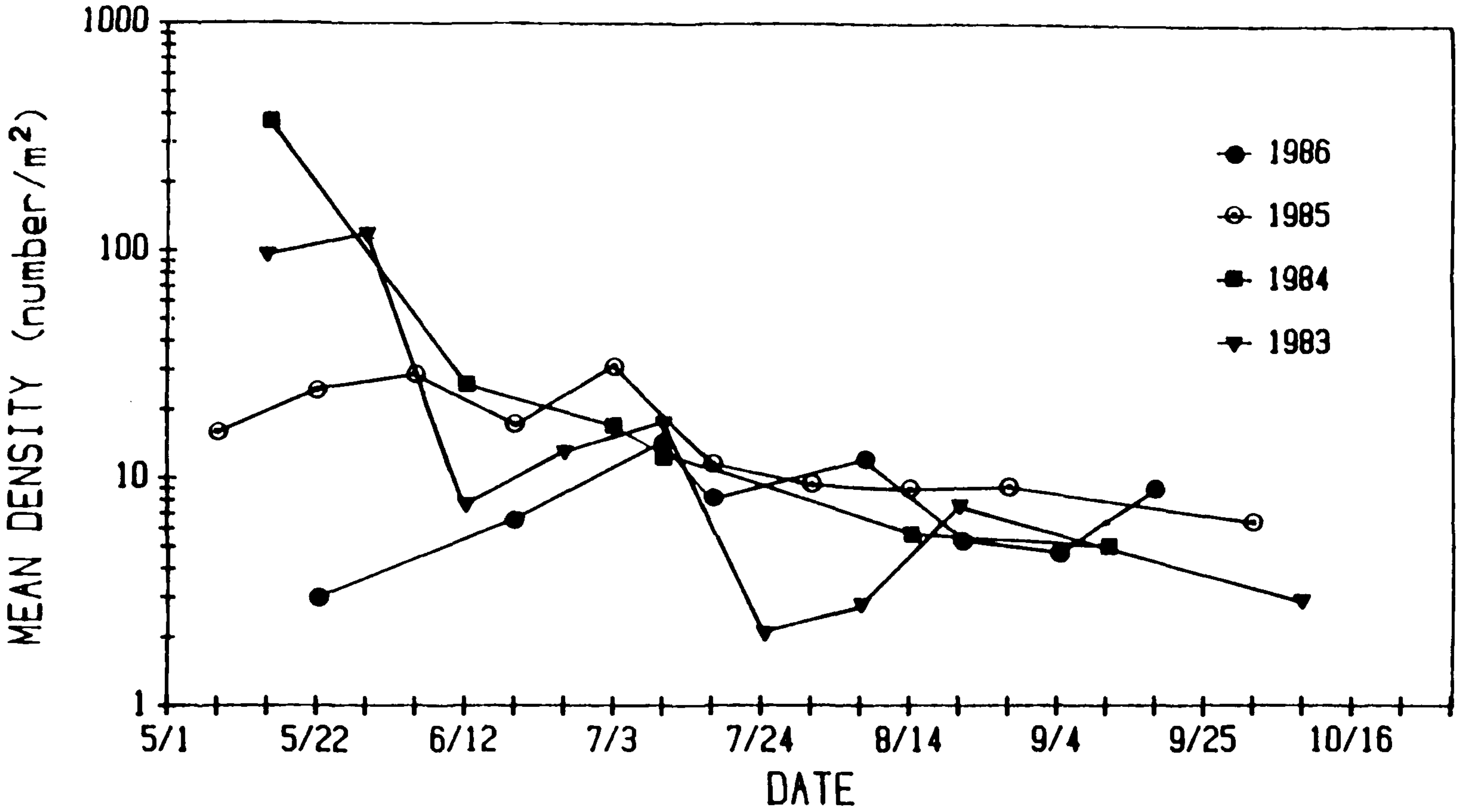


Figure 2.12. Seasonal density of 0+ Dungeness crab in the intertidal area of Grays Harbor, 1983-1986. (Note logarithmic scale.)

within Grays Harbor, population estimates have been calculated for all four years (Fig. 2.13). The high initial densities found in May equate to population estimates of 0+ crab that are as high as 300 million to 1 billion animals. However, more typical numbers, characteristic of the summer between June and September, are in the range of 20 to 40 million animals (Fig. 2.13).

Intertidal population estimates of 0+ crab are, nonetheless, substantially greater than similar subtidal estimates, which are typically an order of magnitude (or more) lower on a four-year mean basis (Fig. 2.14). Population levels tend to converge late in the summer, which is taken as evidence of migration from the intertidal flats to the subtidal as 0+ crab grow larger.

2.3.3 Nearshore

During the time (1983-1986) of estuarine surveys of Dungeness crab abundance, assessments of populations nearshore were conducted simultaneously. To provide nearshore population estimates for the calculation of dredging impact, the original boundaries of the Sea Grant program described by Gunderson et al. (1985) were reduced to the shaded area shown in Figure 2.15, which we assume more closely depicts the spatial boundaries of crab movement between Grays Harbor and the adjacent nearshore (see Section 4.2.1 for more details). Estimated population abundance through the four years (Fig. 2.16) indicates tremendous variability in relative success of settlement and survival of 0+ crab. Several aspects of the data are important to note:

1. Depending on when the surveys begin in spring, nearshore populations are often low but rapidly increase, usually from May to June, as megalopae metamorphose and settle to the benthos.

2. The bulk of the nearshore population (>99%) is composed of 0+ crab in the first several instar stages.

3. There is substantial mortality of these small crab and their numbers are significantly reduced by September, which marks the end of surveys in most years.

4. Settlement and survival in 1983 and 1986 were lowest (abundance generally less than 12 million crab). Populations were strongest in 1984 and 1985, ranging from several hundred million to more than 1 billion animals (Fig. 2.16).

2.4 Population Mixing

There is good evidence of movements of age 1+ and older crab to and from estuarine and nearshore areas. Knowledge of the timing and magnitude of these migrations is of considerable applied interest, but is obviously difficult to obtain.

The calculation of SFDs of age 1+ crabs from estuarine and nearshore areas showed two types of recurring "anomalies" during the summer of the second year of life: a) crab smaller than expected appear suddenly in the samples in the estuary between June and August (Fig. 2.17); and b) crab larger than expected appear in the nearshore samples in mid- and late summer. This anomaly results in a growth rate that is higher than would otherwise be expected for nearshore crab (Fig. 2.18). Since growth rate is lower nearshore than in the estuary, these "size anomalies" might be attributable to migrations between the estuary and nearshore.

Applying the observation (Section 2.2.3) that instar sizes of nearshore and estuarine crab differ after the first winter, it should be possible to discriminate the relative contribution of the two sources in samples containing crab of mixed origin. We attempted this, using an analytic method similar to that described in Section 2.2.2. The results

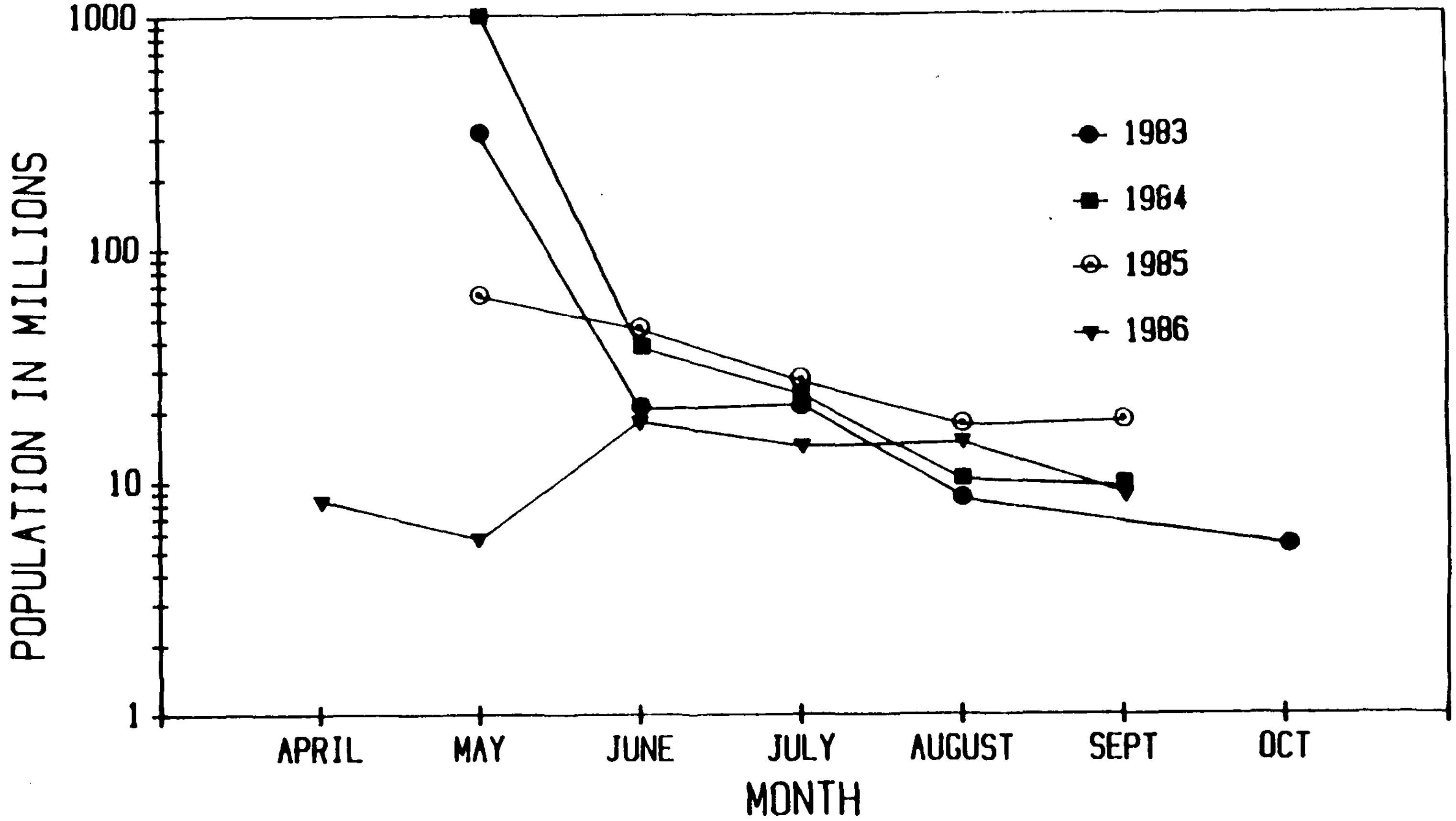


Figure 2.13. Estimated seasonal population abundance of 0+ crab in intertidal areas of Grays Harbor extrapolated to areas shown in Fig. 2.11. (Note logarithmic scale.)

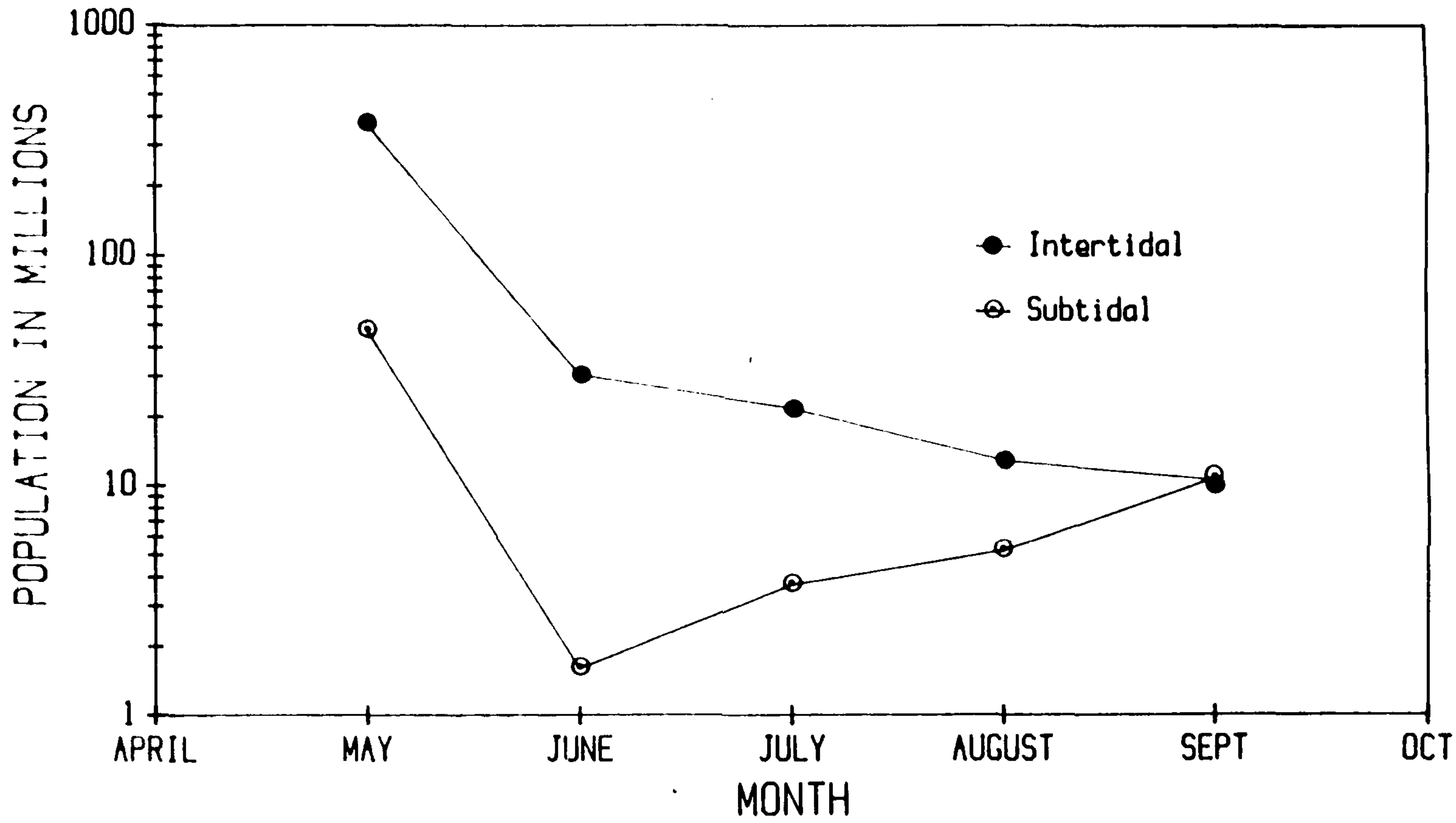


Figure 2.14. Comparison of four-year monthly mean estimated population of 0+ crab in the subtidal and intertidal areas of Grays Harbor. (Note logarithmic scale.)

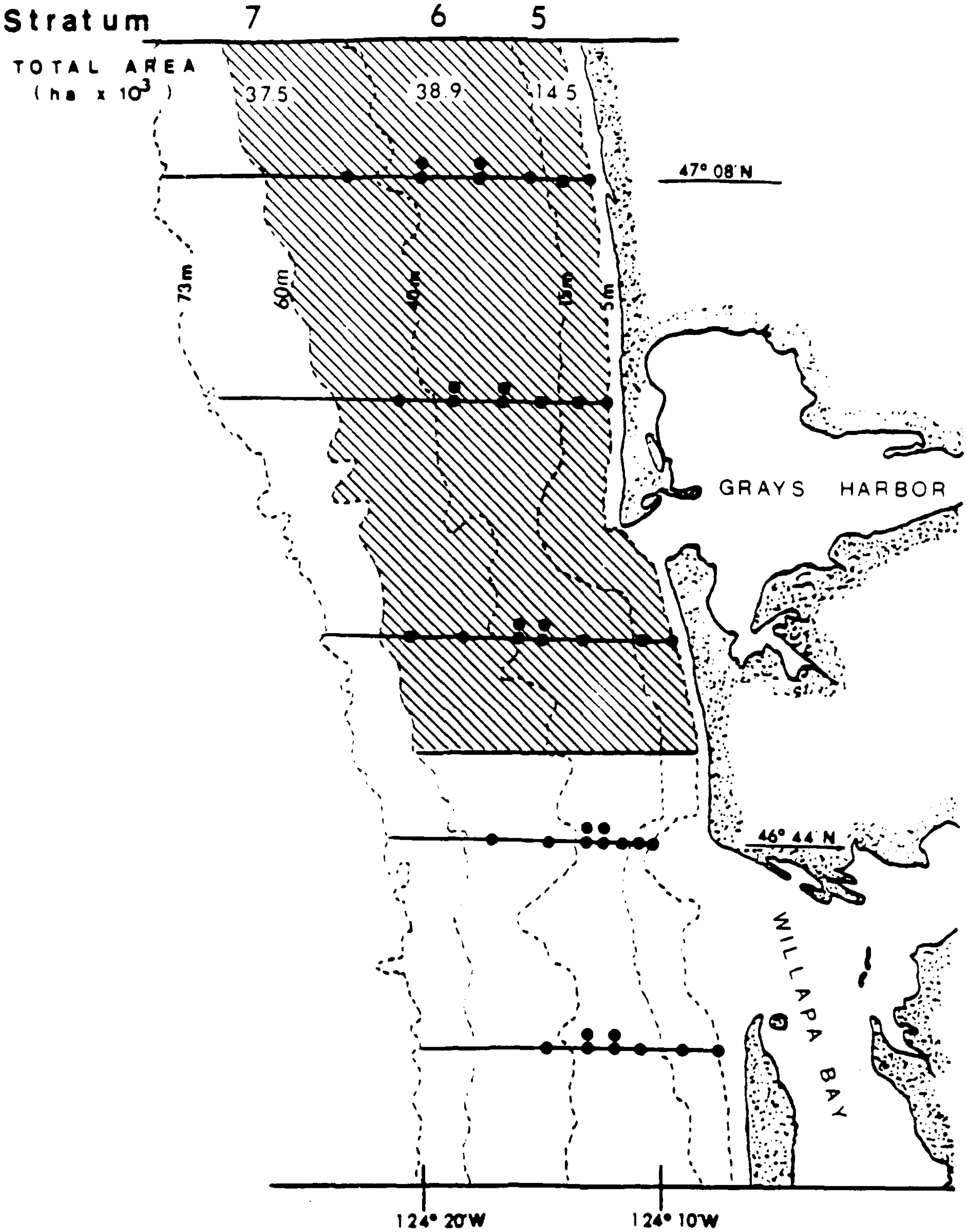


Figure 2.15. Nearshore area (hatched) used to calculate population abundance for use in the impact model as partial basis for estimating percentage loss due to dredging.

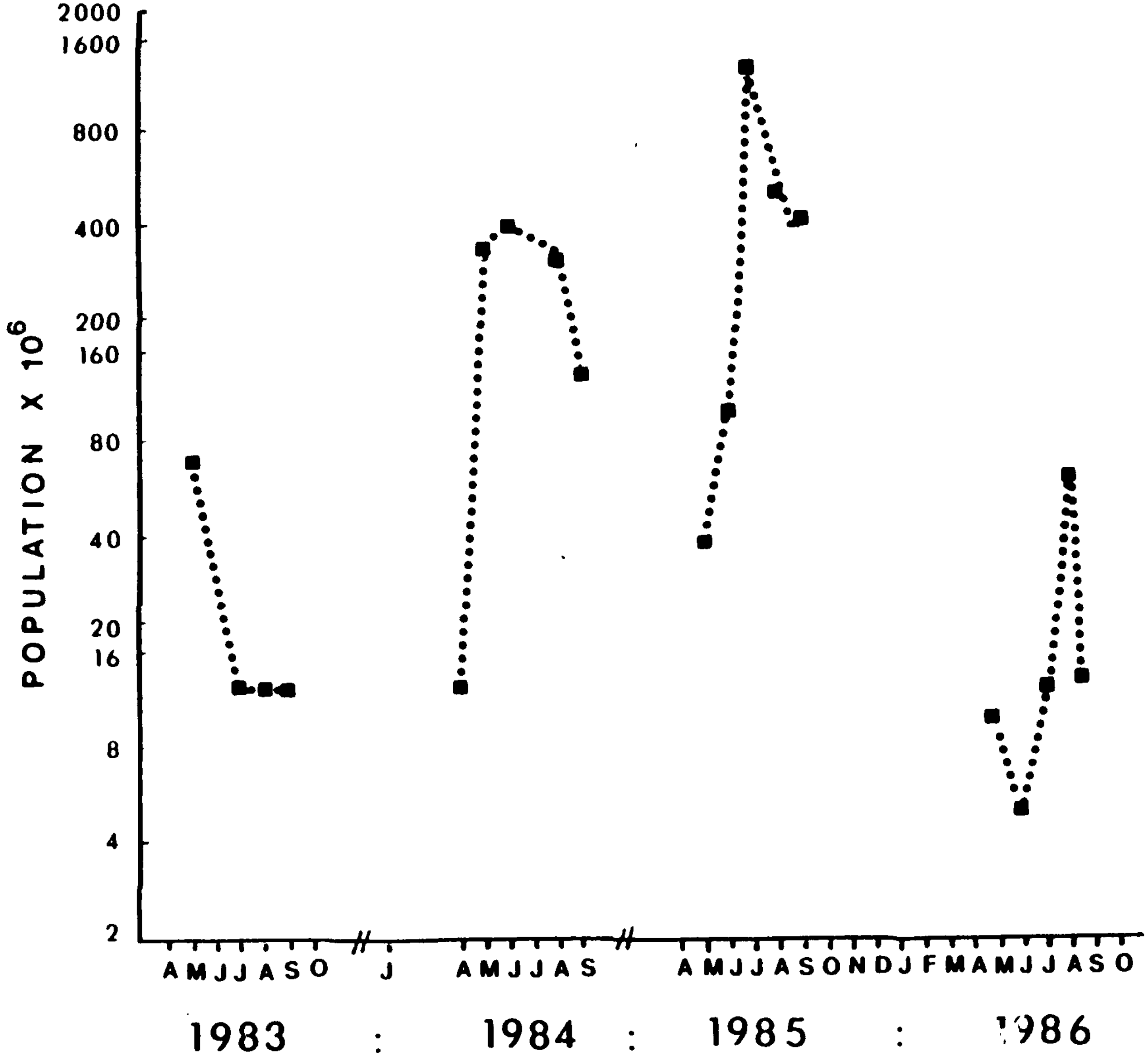


Figure 2.16. Trend in estimated population abundance nearshore over four years. More than 99% of total crab are 0+.

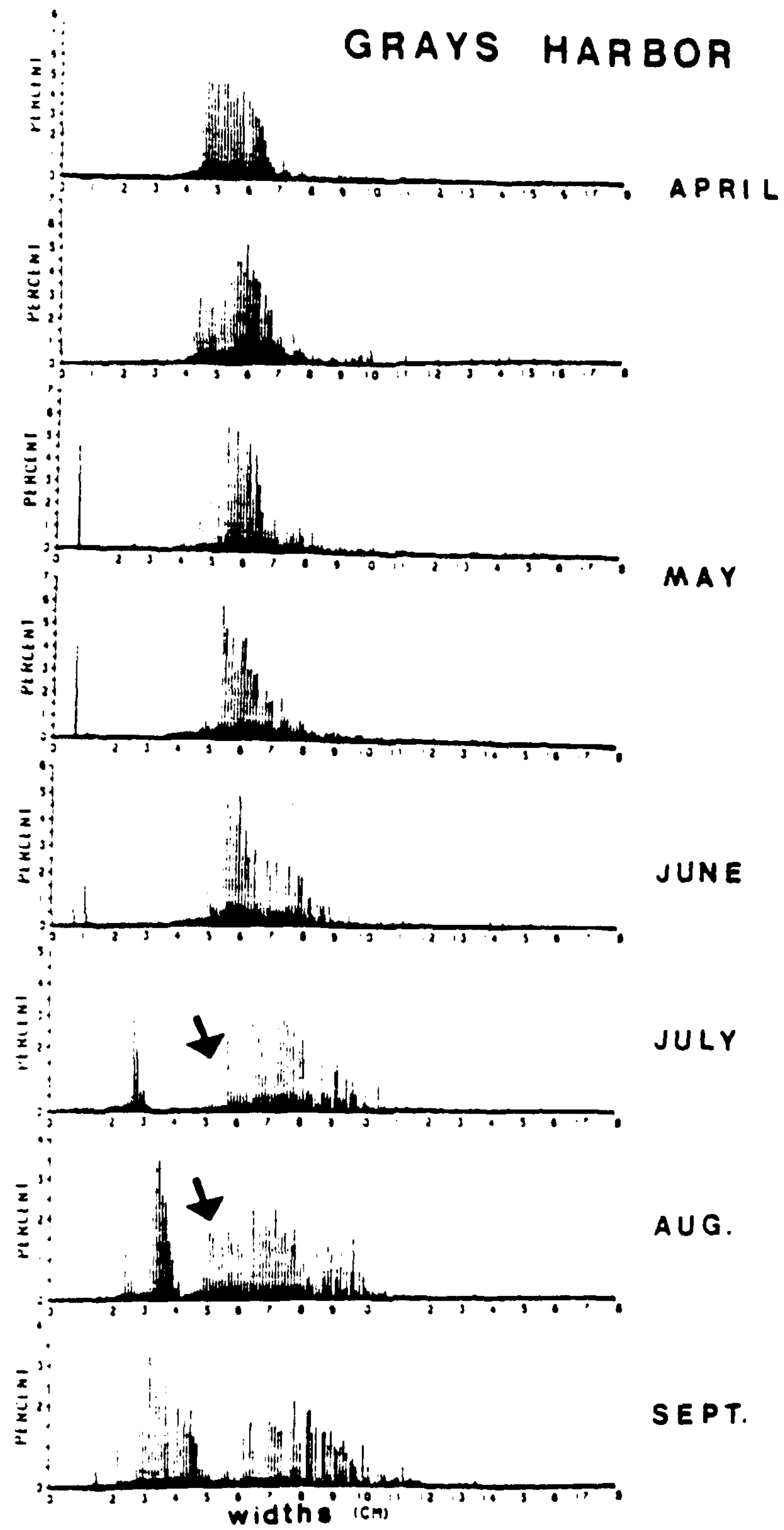


Figure 2.17. Evidence of mixture of estuarine and nearshore crabs in the estuary by late summer, 1985. Arrows point to a modal group composed of instar J-8 nearshore immigrants.

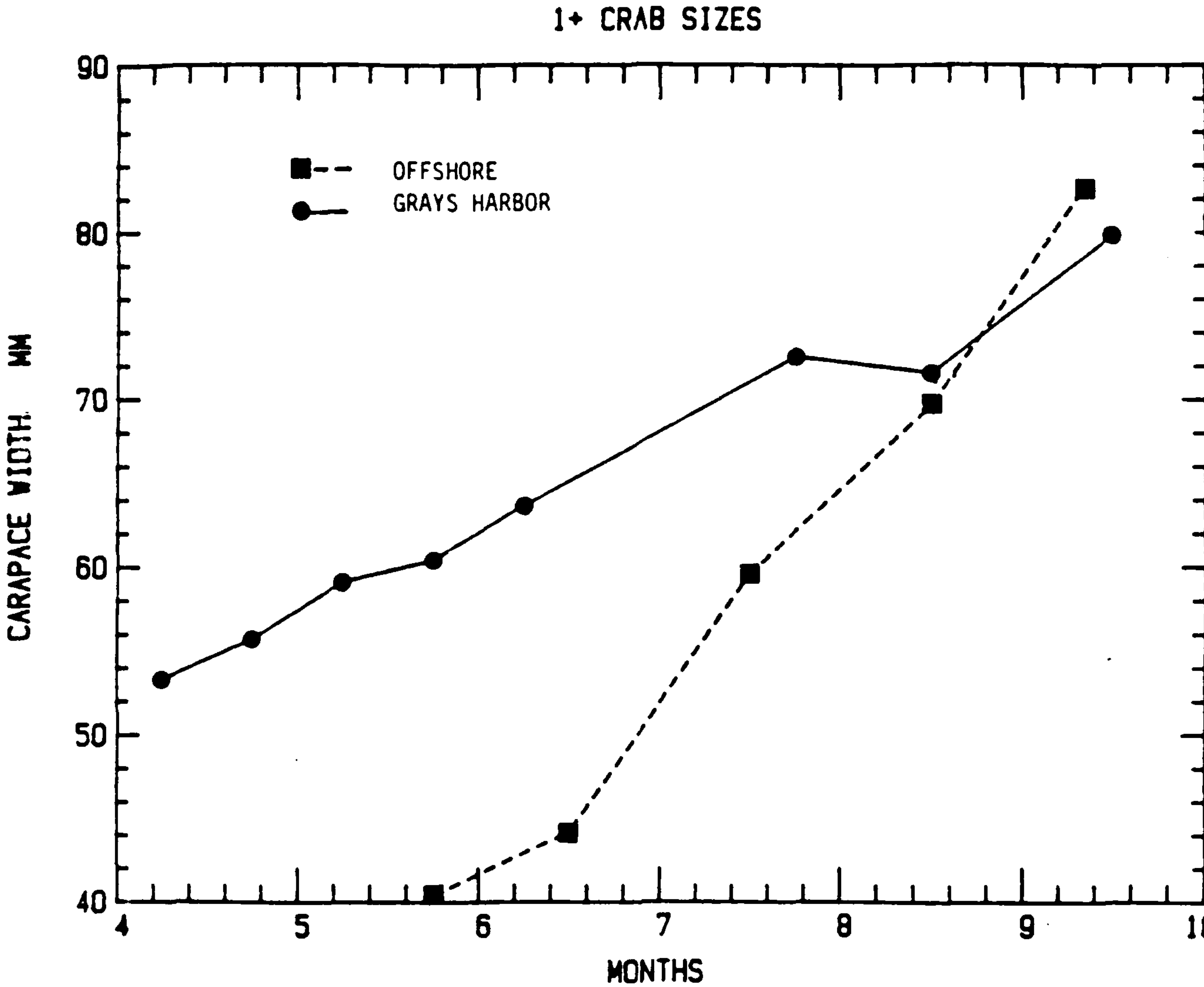


Figure 2.18. Convergence in apparent size of nearshore and estuarine crabs as they approach age 2+ (1985 and 1984 year classes). The pattern is largely attributable to migration of crab in both directions, but more so to movement of large estuarine crab to the nearshore. The groups are already well mixed at age 2+.

obtained are encouraging, and give one possible interpretation of the levels of mixing of the two subpopulations. For 1+ crab in the estuary in late summer, those of nearshore origin were 50% in 1983 and 1985, about 80% in 1984, and almost 100% in 1986. Mixing of nearshore and estuarine young-of-the-year crab may start as early as in October in areas close to the mouth of the estuary, as shown by the SFD of crab sampled in a proposed dredged materials disposal site by Dinnel et al. (1986a, Fig. 5, bottom). The "nearshore wave" is detectable in the estuarine data with a variable timing (June to August) and nearshore crab are instar J7 (about 40 mm CW) or J8 (about 52 mm CW). This phenomenon was also detected in the data from 1981 obtained by Stevens and Armstrong (1984). That year, nearshore J7 instar crabs showed up in the estuary in May as was the case in 1983. The idea that the discrepancy between size-at-instar schedules from nearshore and estuarine populations can be useful in understanding population mixtures was an unexpected outcome of this study. However, the technique has not yet been fully tested, so these results should be used with caution.

In light of these analyses of size-at-instar schedules, growth, rates, patterns in size-frequency plots, and the distinct differences in these parameters between estuarine and nearshore populations, an improved synopsis of timing of movement and residency between and within estuary and nearshore is shown in Fig. 2.19 (which expands on Fig. 2.1). All reproductive events occur along the coast, where larvae hatch and develop. Megalopae settle nearshore or enter the estuary in late spring. Estuarine 0+ crab best survive on intertidal flats in shell habitat, and throughout the estuary growth of 0+ crab is much greater than that of siblings nearshore. Beginning in late summer (or earlier, depending on size), 0+

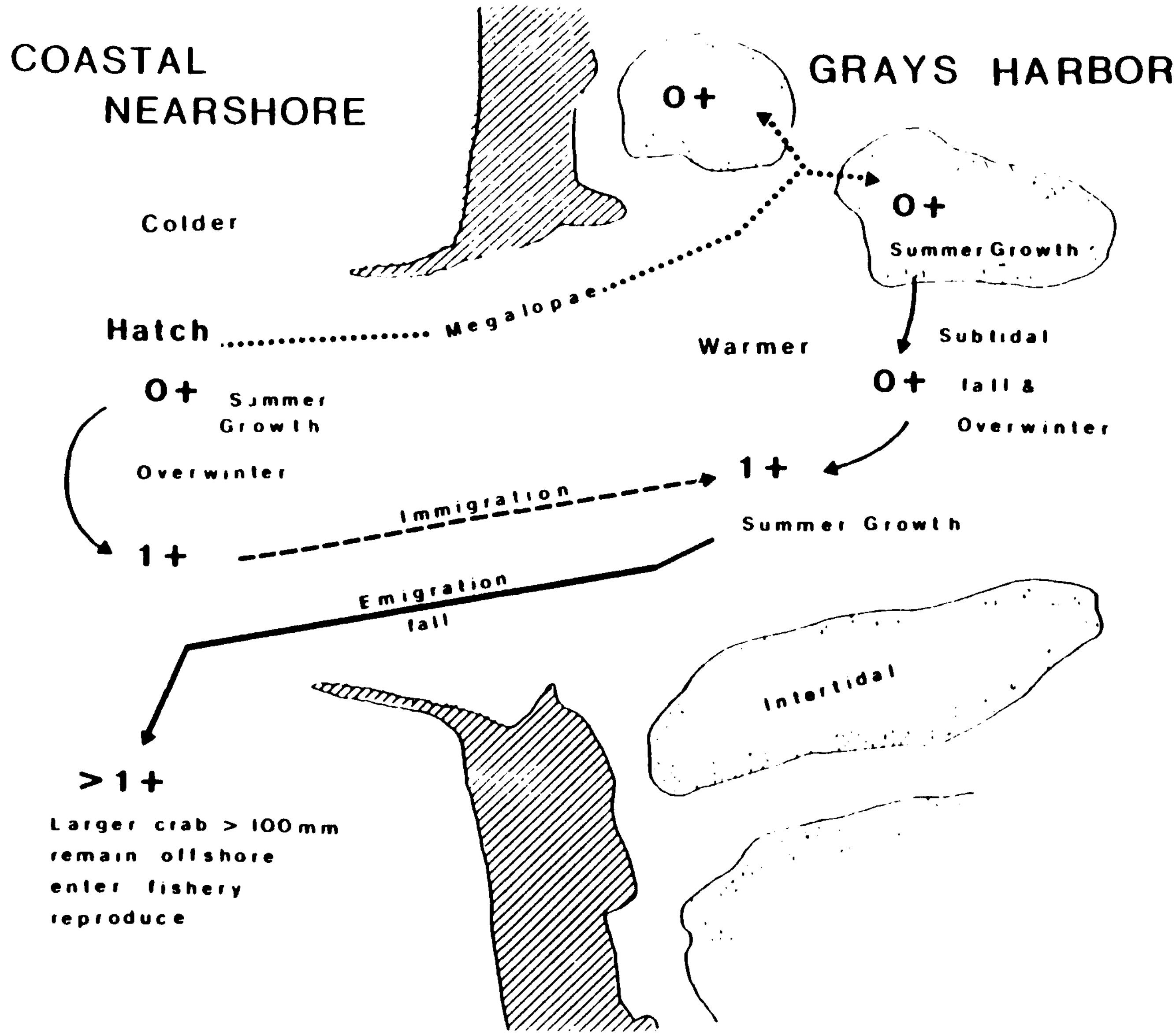


Figure 2.19. Refined schematic (see Fig. 2.1) showing generalized movements of juvenile Dungeness crab to and from Grays Harbor and the nearshore environment.

crab leave the intertidal flats and move to adjacent subtidal channels where they overwinter and grow very little. In their second spring, 1+ crab are located in two areas: the estuarine subtidal or nearshore, depending on settlement patterns the previous year. A portion of the nearshore (coastal) 1+ crab immigrate to the estuary where growth is enhanced (relative to colder nearshore areas) in early summer to join the resident 1+ population. As crab reach sizes near or greater than 100 mm CW, they emigrate from the estuary during late summer and fall of their second year. They do not return again in appreciable numbers. Females near 100 mm will molt and breed the following spring (as 2+ crab); males larger than 110-120 mm CW generally remain in coastal waters, but may mix somewhat across the estuarine mouth.

2.5 Survival

2.5.1 Data

Data used to estimate survival include: 1) monthly assessments of crab abundance (see Section 2.3), and 2) estimates of the proportion contributed by each instar to the total sample from each month or cruise.

The instars were grouped into age classes, according to the growth patterns described above (Section 2.2.4), and abundance per age class was calculated for each month. The values assembled in this way have a number of acknowledged limitations:

1. The confidence intervals for the monthly abundance estimates are so wide [two standard errors (2 SE) represent about 40-50% of the mean in the estuary and up to 80-100% of the mean nearshore] that the values should be seen only as indications of abundance.
2. The gear utilized in the surveys is not 100% efficient, and there is evidence that efficiency depends on the size of the crabs, especially for large (above 120 mm CW) crabs.

3. There may be a seasonal component in the catchability of crabs of all sizes. Catches are generally lower in winter and early spring than in summer, which may be related to winter burial of crabs or other seasonal changes in behavior.

Three sets of monthly abundance estimates were used in calculating survival estimates for the study area:

1. Nearshore areas defined in Section 2.3.3;
2. Subtidal areas of the estuary (see Section 2.3.1); and
3. Intertidal areas of Grays Harbor (Section 2.3.2).

2.5.2 Survival of 0+ Crabs Within the Estuary

The data used here include crabs within the estuary, both subtidal and intertidal, from settlement through July of the second calendar year of life. The data indicate two very different segments in this part of the life history: 1) the first month of benthic life, and 2) the rest of the first year of life.

During the first month mortality can be extremely high, particularly in years when initial settlement is high (see Section 2.3.2). This was apparent for two years (1983 and 1984) in which there were huge intertidal settlements followed by severe postsettlement declines (93-96% in one month). For these reasons the data from May 1983 and May 1984 were excluded from the analyses. Early survival of very large estuarine cohorts requires ad hoc treatment.

The rest of the data fit the usual exponential decline model rather well. The model may be expressed as:

$$dN/dt = -ZN \quad (1)$$

where N is population size, t is time (in years), and Z is the total instantaneous mortality coefficient. To estimate Z, each monthly abundance

estimate (N) was divided by the initial abundance (N_0) of the respective year class. N_0 was taken as the abundance of 0+ crabs in the month of peak settlement in 1985 and 1986, or one month following peak settlement in 1983 and 1984 (for the reasons explained above). Then, Z was estimated by simple linear regression of the logarithm of N/N_0 on age (Fig. 2.20). Results were as follows:

$Z = 3.047/\text{yr}$, significance = 0.00001

$r^2 = 77.8\%$, $n = 24$

Survival (S) = 3.3% for the first year.

2.5.3 Survival Throughout the Whole Region (All Ages)

Given the limitations of the data outlined above (Section 2.5.1), the estimation procedure is inevitably coarse at this stage and is intended only to give a broad idea of the mortality pattern. Only the nearshore and subtidal estuary data were utilized. Because 0+ intertidal crabs are excluded, this approach overestimates survival during the first year of life. Monthly abundance estimates for the estuary and nearshore were combined. Data for months in which only one area was sampled were discarded. All monthly values for each age class were averaged across year classes, and then all the monthly averages corresponding to each age class were averaged for the four years of the survey to give an overall average $\overline{N}$ for each age class (all year classes combined) during the survey season (April to October). The resulting $\overline{N}$ values were utilized to calculate summer-to-summer age-specific S and Z values. The resulting values are shown in Table 2.4.

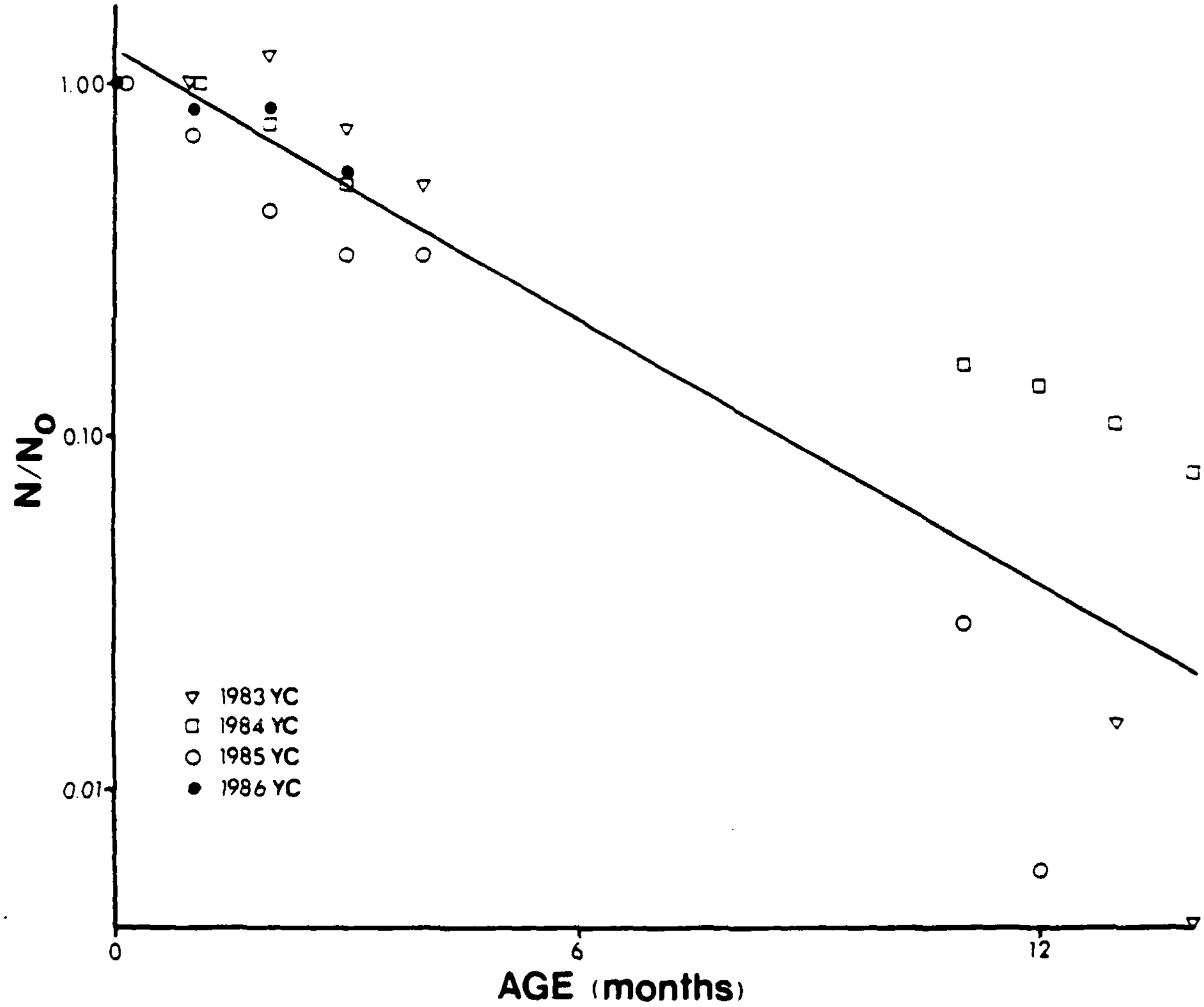


Figure 2.20. Survival of 0+ crabs within the estuary for four year classes (YC). Solid line is the predicted regression. Age is measured from the month of peak settlement.

Table 2.4. Estimated mean population for five age classes of Dungeness crab based on the combined nearshore and estuarine population information from the four year Sea Grant survey, 1983-1986. Annual survival rate (S) and mortality rate (Z) are shown and correspond to results depicted in Figure 2.21.

AGE	$\bar{N}$ (millions)	S (% per year)	Z (per year)
0	186.167		
		10.2	2.28
1	19.074		
		16.2	1.82
2	3.089		
		23.4	1.45
3	0.724		
		38.0	0.97
4	0.275		

Figure 2.21 illustrates the decay of the $\bar{N}$ values and of their logs over time, and Z as a function of age. The four Z values are linearly related to age; regression of Z on age gives the following result:

$$Z = 2.49 - 0.43 \text{ (age)}$$

This age-dependent Z implies the survival model:

$$dN/dt = -(a + b \times \text{age})\, N \qquad (2)$$

which, integrated, gives

$$N(t) = N_0 \times \exp[-(a+b/2 \times \text{age})t] \quad (3)$$

There is agreement among specialists that Z should decrease monotonically as a function of age. The function obtained here agrees with two "educated guesses" from the literature: 1) a survival below 10% for the early life history (initial survival is 8% in the line fitted), and 2) a natural survival of 80% per year for large crab about 5 years old (Armstrong et al. 1984; Botsford and Wickham 1978).

Pooling year classes may distort the pattern if a strong year class is well represented for a part of the life history. Given that the strong 1984 year class has, so far, been sampled for three years (1984-1986), its

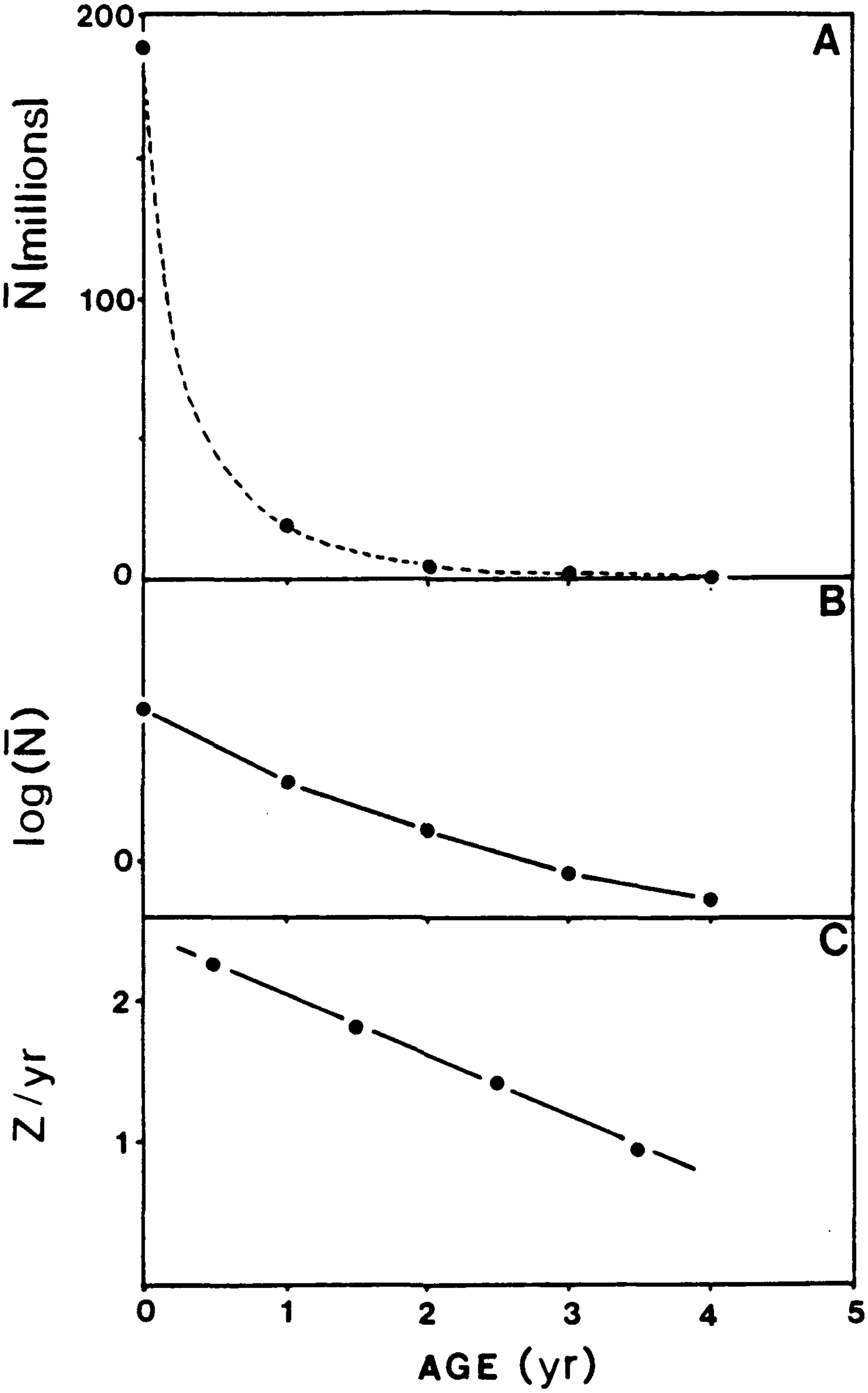


Figure 2.21. Survival for the whole study area, Grays Harbor plus nearshore (intertidal excluded). A: Average survival curve. B: Same, with logarithmic scale (notice that points do not fall on a straight line). C: Age-dependence of the mortality coefficient (Z).

inclusion in the overall averages might be expected to depress the estimation of survival from age 2+ to 3+. This might happen if inclusion of the 1984 year class causes the estimated annual mean abundance of 0+, 1+, and 2+ to be high relative to abundance of 3+ and 4+ that come from other year classes. As a test of this, the analysis was redone excluding the 1984 year class. In comparison with the results from the full data set, this analysis showed:

1. Survival from 0+ to 1+ (4.6%) is lower.
2. There is not much change in survival from age 1+ to 2+ (19.5% here; 16.2% Table 2.2).
3. As expected, survival from 2+ to 3+ is higher (45.0% versus 23.4%).
4. Survival from age 3+ to 4+ remains the same, simply because the 1984 year class did not enter into the previous analysis.
5. The decrease in survival after age 3+ may reflect the fact that at least part of the males are recruited to the fishery at age 3.5 years (see Section 2.2.5). Thus, the mortality coefficient (Z) from age 3+ to 4+ might include both natural and fishing mortality components.
6. The new set of Z values does not appear to show a simple linear relationship with age.

Clearly, the sensitivity of our mortality estimates to year-class strength, along with the data limitations outlined in Section 2.5.1, indicate that improved estimates would be desirable. These coarse analyses, if nothing else, show that there is an underlying pattern. Given the extreme rarity, high cost, and great value of accurate knowledge of natural mortality, additional efforts to improve data applicability, and to use more rigorous estimation techniques, should be given a high priority in future research programs.

3.0 DREDGE ENTRAINMENT STUDIES

3.1 Entrainment Rates

A variety of Dungeness crab entrainment studies have been carried out in the last 10 years; most have been conducted in Grays Harbor. These studies were initiated in 1975 by Tegelberg and Arthur (1977), who estimated crab entrainment rates by the hopper dredge Biddle. This study was followed by the work of Stevens (1981) who provided entrainment data for the hopper dredges Sandsucker and Pacific, the pipeline dredge Malamute, and the clamshell dredge Viking. Armstrong et al. (1982) continued the work initiated by Stevens to produce additional entrainment data for the hopper dredge Sandsucker and the pipeline dredges Malamute and McCurdy.

All the above-cited studies produced estimates of crabs entrained per cubic yard of solids dredged, but these studies were not designed to provide side-by-side comparisons of crab entrainment with in situ crab densities, information which is necessary to derive entrainment models for predicting future dredging impacts. To alleviate this lack of data, the Corps of Engineers sponsored crab entrainment studies aboard the hopper dredge Yaquina in Grays Harbor in 1985 and 1986 (McGraw et al. 1987). In conjunction with these studies, side-by-side trawling work was conducted by Dinnel et al. (1986a,b) to provide in situ crab density estimates which could be directly compared to the crab entrainment per cubic yard data generated by the dredge sampling.

The crab entrainment rates determined by each of these studies are summarized in Table 3.1. Hopper dredge entrainment rates ranged from a low of 0.046 to a high of 0.587 crab/cy of dredged material in Grays Harbor, although one study in the Columbia River estuary found an average entrainment rate of 11.0 crabs/cy, almost all of which were small young-of-

the-year crabs (C.O.E. 1986). Pipeline dredges in Grays Harbor have entrained a range of 0.002 to 0.243 crab/cy. To date only one study (Stevens 1981) has estimated a clamshell dredge entrainment rate, which was 0.012 crab/cy.

3.2 Entrainment in Relation to Crab Densities

Any crab entrainment model designed to predict dredge entrainment losses must address such dynamic variables as dredge type, dredging season, location, crab density fluctuations (annual and seasonal), and mortality specific to each dredging method. One of the most important variables is the function relating dredge entrainment with in situ crab densities. As noted above, most dredge studies in Grays Harbor have only produced crab entrainment rates per cubic yard of material dredged without any direct measures of actual crab densities associated with these rates.

Armstrong et al. (1982) made the first attempt to relate entrainment rates to actual crab densities by comparing site-specific entrainment to trawl-generated measures of crab abundances in the general areas of dredging (Table 3.2). However, these crab abundance measures were far enough removed in space and time from the actual dredging that their usefulness in a predictive model is questionable.

Dinnel et al. (1986a) conducted trawling for crab side-by-side with the hopper dredge Yaquina (McGraw et al. 1987) to remedy this lack of comparative data. It is these data that presently provide the most reliable entrainment versus crab density comparisons (Table 3.2) and, hence, form the basis of the entrainment-versus-density curves calculated in Section 4.0.

Table 3.1 Summary of estimated dredge entrainment rates for hopper, pipeline, and clamshell dredges operating in Grays Harbor during past dredge studies. Also listed is one pipeline dredge study in British Columbia, and one hopper dredge study from the Columbia River.

Dredge Type/Study	Sample Period	Dredge	Area Dredged	Sample Size (Approx. Cubic Yards of Solids Dredged)	Average Number of Crabs Entrained/Cubic Yard Dredged
Hopper Dredge:					
Tegelberg and Arthur 1977	March, 1975	Biddle	Old West Reach	78	0.449
Stevens 1981	Nov-Dec, 1978	Sandsucker	South Reach	463	0.231
	March, 1979	Pacific	Crossover and South Reaches	1,058	0.182
Armstrong et al. 1982	Summer, 1980	Sandsucker	Cow Point	36	0.079
			North Channel	76	0.107
			Crossover Channel	197	0.075
			South Beach	313	0.502
McGraw et al. 1987 & Dinnel et al. 1986a,b	18 Oct 1985	Yaquina	South Reach	648	0.046
	22-23 Oct 1985	Yaquina	Crossover and South Reaches	372	0.118
	1-3 Aug 1986	Yaquina	Crossover Channel	114	0.070
			East South Reach	237	0.587
			West South Reach	406	0.143
C.O.E. 1986	Summer, 1985	Essayons	Columbia River Bar	Unknown	11.000*
Pipeline Dredges:					
Stevens 1981	Sept-Nov, 1979	Malamute	Westport Marine	321	0.243
	Nov-Dec, 1979		Terminal 4, Aberdeen	584	0.002
Armstrong et al. 1982	April-May, 1980	Malamute	Cow Point	357	0.015
	Feb-March, 1981	McCurdy	Cow Point	934	0.020
Archibald 1983	1981-1983	Sceptor Fraser			0.005
		King Edward			0.007-0.026
Clamshell Dredge:					
Stevens 1981	Oct&Dec, 1978	Viking	Crossover and South Reaches	86	0.012

*99.9% young-of-the-year crabs of <25 mm CW.

Table 3.2 Sources of Dungeness crab density estimates and hopper dredge entrainment rates used for the linear and curved entrainment functions illustrated in Figure 4.2. Only the values from Dinnel et al. 1986a,b are used to calculate the regressions. Values from Armstrong et al. 1982 are included in Fig. 4.2 for reference only.

Data Source	Dredge	Area	Sample Period	Trawl-Estimated Crab Density (crab/ha) (assuming 100% efficiency)	Dredge Entrainment (crab/cy of dewatered solids)
Armstrong et al., 1982	Sandsucker	South Reach	7/80	1,550	0.502
		Cow Point	6/80	270	0.079
		Moon Island	8/80	20	0.017
		Crossover Reach	5/80-9/80	810	0.075
Dinnel et al., 1986a*	Yaquina	South Reach	15-18 Oct 1985	506	0.046
		"	22-23 Oct 1985	773	0.118
Dinnel et al., 1986b*	Yaquina	South Reach	1-3 Aug 1986	816	0.135
		"	"	1,413	0.592
		Crossover Reach	1-3 Aug 1986	639	0.088

*Using entrainment data provided by COE (McGraw et al. 1987). Entrainment data for 15-18 October 1985 came from preliminary sampling (K. McGraw, personal communication).

3.3 Entrainment Mortality

A crab entrained by a dredge is not necessarily killed. Mortality rates depend on dredge type, disposal methodology, crab sizes, and the condition of the crab (i.e., degree of softness of the shell as related to molting).

Armstrong et al. (1982, p. 206) reported differential mortality rates (corrected for sampling-induced mortality) based on size for hopper dredge-entrained crabs. They found that 86% of crabs larger than 50 mm CW died following entrainment but that crabs smaller than 50 mm suffered a mortality rate of 46%. Experimental laboratory studies and direct observations aboard the hopper dredge Essayons on the Columbia River Bar by the Corps of Engineers (K. Larson, personal communication) have suggested that a mortality rate in the range of 1% to 5% is realistic for very small (<10 mm CW) young-of-the-year crabs. For use in this impact analysis, the Crab Study Panel (1986) adopted a set of size-dependent mortality rates, which form a smooth progression from 5% mortality for very small crab to 86% for large crab (Table 3.3).

Relatively little mortality information exists for clamshell dredges. Stevens (1981) estimated that clamshell dredge-induced mortality was only about 10% of all crab sizes. In the absence of any other data, this mortality value for the clamshell dredge will be applied in the following impact analysis.

Pipeline dredges represent a special case. Effluent from pipeline dredges is usually to confined upland disposal behind dikes, hence crab mortality is 100% of those crab entrained (Stevens 1981). The primary question relating to pipeline dredges is the relationship between entrainment/cy dredged versus in situ crab densities. Presently, no experimental data of this type is available for pipeline dredges. Pot and

Table 3.3. Sources of Dungeness crab mortality rates for each dredge type used in the dredge impact analysis.

Data Source	Age Class	Crab Size Range (mm)	Season	Estimated Percent Mortality
Hopper Dredge:				
Larson (personal communication)	0+	7-10	Spring	5
Crab Study Panel 1986	0+	11-30	Summer	10
	0+	31-40	Fall	20
	0+	41-50	Winter	40
	1+	51-75	Spring-Summer	60
Armstrong et al 1982	1+	>75	Fall-Winter	86
	>1	>75	All	86
Clamshell Dredge:				
Stevens 1981	All	All	All	10
Pipeline Dredge:				
(Confined Disposal)				
Stevens 1981	All	All	All	100

ring samples near a pipeline dredge were reported by Archibald (1983), but these do not provide useful estimates of crab density. Therefore, in the absence of such data, the following impact analysis sets pipeline dredge entrainment equal to hopper dredge entrainment rates and pipeline mortality equal to 100%. (We also consider a reduced pipeline mortality rate in Section 5.3).

4.0 DESIGN OF THE MODEL AND ASSUMPTIONS

4.1 Overview of the Entrainment Model

Figure 4.1 summarizes the main components of the model by which crab are entrained, killed, and eventually seen as a loss to the local fishery. Details of individual components are discussed in Section 4.2. There are two major inputs to the model: 1) observations of crab abundance, categorized by age class (0+, 1+, >1+), season, and location; and 2) the dredge schedule, giving volumes dredged by type of equipment (hopper, clamshell, or pipeline), season, and reach. These two data sets are combined through an entrainment function that estimates the number of crabs entrained when a specified volume is dredged by a specified gear in an area with a certain total (all age classes combined) local abundance of crab. This entrainment is then proportioned among the three age classes on the basis of their proportions in the local population. This calculation provides the number of crabs of each age entrained in a given location and season.

From these numbers of crab entrained, number of crab killed by dredging is calculated from dredge mortality rates for the three types of equipment. Finally, to put crab loss for each age and season on an equal basis, these "immediate loss" (IL) numbers are multiplied by the expected survivals (Section 2.5) of crab from any age and season to the winter of their 2+ year (in doing this we have assumed that there are no significant numbers of 3+ or older crab in the Grays Harbor subtidal). These "loss at age" figures can then be expressed either as absolute numbers lost, or as a percentage of the local population. A more detailed description of these calculations is given in Appendix C.

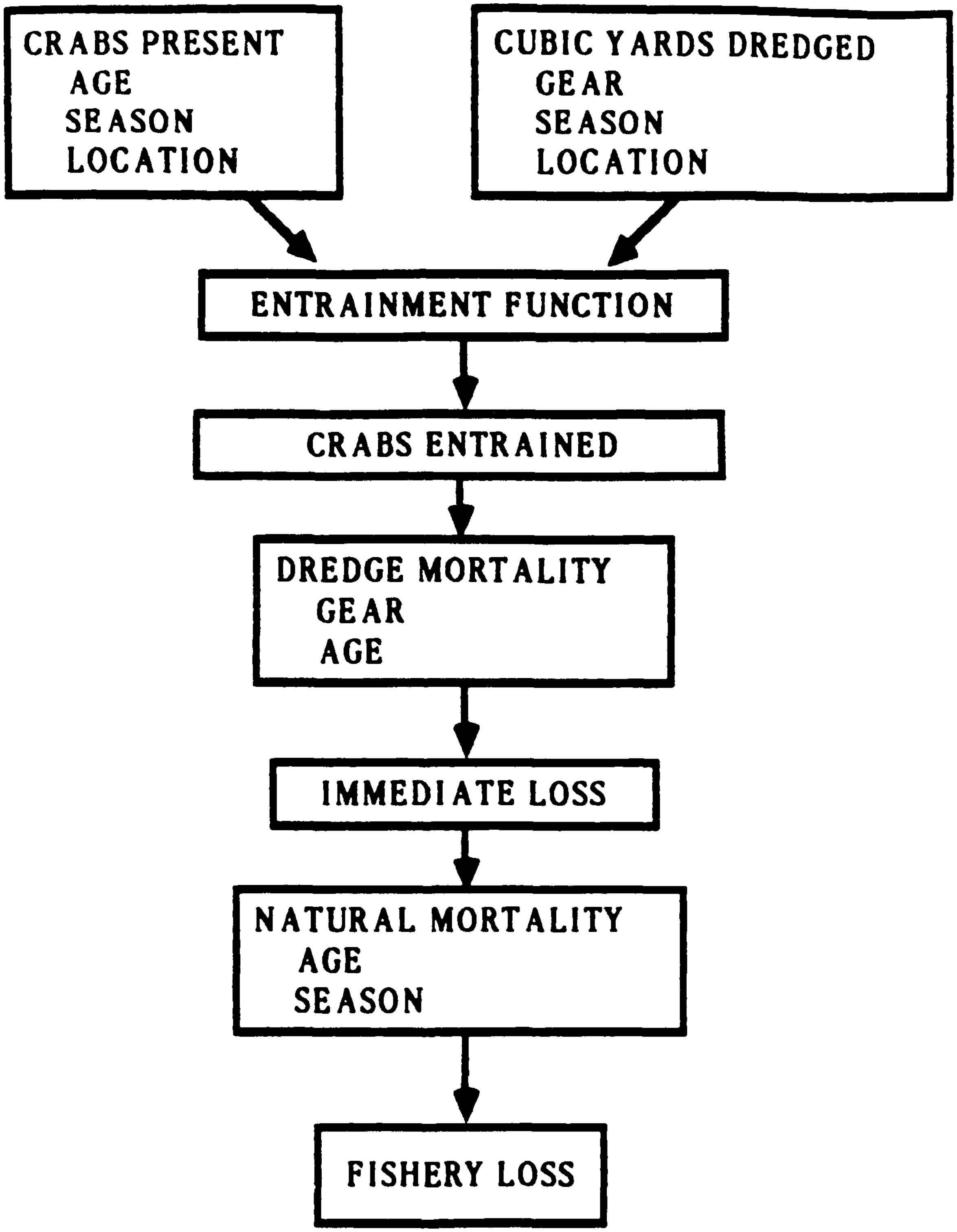


Figure 4.1. Components and steps of the impact model used to estimate loss of crab under various scenarios of population abundance and dredging schedules.

4.2 Use of Data and Parameter Estimates

4.2.1 Population Abundance

From the four years of crab population surveys in and around Grays Harbor (Section 2.3), we obtained estimates of mean population density (crab/ha) for each sample month in each sampling area (stratum). Each monthly mean reflects the results of several trawl samples within each stratum. Total population estimates were obtained by multiplying these estimated density values by the total area of each stratum, then adding values for all strata. Of the total coastal crab data set (including Grays Harbor, Willapa Bay, and a substantial portion of the Washington coast), we have used only data from Grays Harbor (intertidal and subtidal areas) and the northern portion of the nearshore sampling area (Fig. 2.15). The nearshore area used is that most likely to be influenced by crab immigrating to or emigrating from Grays Harbor, and excludes the area most closely connected with Willapa Bay. Crab populations were sampled during the spring and summer in 1983 through 1986, but were sampled in the fall and winter only in the Grays Harbor subtidal areas and only during two years (1983-1984 and 1985-1986). Data from 1980-1981 (Stevens and Armstrong 1984) were also used for comparison.

Population estimates for each stratum were then broken down into age classes. Proportional age class composition for each month and each stratum was estimated by modal analysis of size-frequency distributions (Section 2.2). Total population numbers multiplied by proportions of each age class then give population by age, month, and stratum.

These population estimates show a substantial amount of unpredictable month-to-month variation (for example, see Figs. 2.9 and 2.10), but certain seasonal patterns are apparent. To simplify calculations, we combined monthly data into seasons that reflect important biological processes and

patterns of crab abundance. As a consequence of this, variability in the data was reduced. Beginning with spring, the April-May season reflects the start of settlement for a new age class (0+), and the period of spring migration for older crab (see Sections 2.1 and 2.4). The summer (June-September) is a period of continued settlement and steady mortality for 0+ crab and of relative stability for older crab both in Grays Harbor and nearshore. We have little data for the fall (October-December) and winter (January-March) seasons, but these are periods of both general population decline (due to mortality) and migration from intertidal to subtidal (for 0+) and into and out of Grays Harbor (for older crab) (Fig. 2.19). Tables 4.1, 4.2, and 4.3 show these seasonal population estimates for the four study years and Table 4.4 shows four-year average crab densities for the two areas of Grays Harbor where dredging will take place.

For the analysis presented below, it was necessary to derive population values for the fall and winter in those years for which we did not have data. The data fall into two classes: 1) nearshore and estuary intertidal, for which we have no overwinter data; and 2) estuary subtidal, for which we have some fall and winter data. In the first case, lacking evidence to the contrary, we have simply assumed that the nearshore and intertidal subpopulations decline over the winter as would be expected from natural mortality (Section 2.5). For the Grays Harbor subtidal, the two years of available data (1983-1984 and 1985-1986) showed consistent trends, so we have applied the mean trend from these two years to the subtidal data in other years. From these assumed trends, we have projected fall and winter levels for the various subpopulations (estuary subtidal strata, estuary intertidal, and nearshore) from their levels during the previous summer. This was done by multiplying the summer levels by "conversion

Table 4.1. Estimated seasonal crab populations in Grays Harbor, subtidal and intertidal combined. Data are means of all surveys during the season. Values in parentheses are projected from June-September values, as described in text.

GRAYS HARBOR POPULATION (MILLIONS)

	1983/84	1984/85	1985/86	1986/87	MEAN
0+ CRAB					
APRIL-MAY	160.7	638.3	31.3	7.0	209.4
JUNE-SEPT	22.0	29.7	28.6	14.5	22.6
OCT-DEC	10.4	(17.2)	(11.8)	(5.8)	12.1)
JAN-MARCH	(4.1)	(10.8)	(6.4)	(3.0)	(6.9)
1+ CRAB					
APRIL-MAY	5.0	0.2	6.3	1.1	3.2
JUNE-SEPT	11.8	5.1	5.2	5.2	6.9
OCT-DEC	4.5	(2.7)	3.8	(2.7)	(3.6)
JAN-MARCH	(2.3)	(0.7)	2.0	(0.7)	(0.7)
>1+ CRAB					
APRIL-MAY	3.1	1.0	0.6	0.9	1.4
JUNE-SEPT	2.1	1.5	0.3	1.5	1.3
OCT-DEC	2.3	(1.3)	0.3	(1.3)	(1.2)
JAN-MARCH	(0.6)	(0.4)	0.1	(0.4)	(0.3)
TOTAL					
APRIL-MAY	168.8	639.5	38.2	9.0	214.0
JUNE-SEPT	35.9	36.3	34.1	21.2	30.8
OCT-DEC	17.1	(21.2)	(15.9)	(9.8)	(16.9)
JAN-MARCH	(7.0)	(11.9)	(8.5)	(4.1)	(7.9)

Table 4.2. Estimated seasonal crab populations for nearshore subtidal area adjacent to Grays Harbor. Data as in Table 4.1.

	NEARSHORE POPULATION (MILLIONS)				
	1983/84	1984/85	1985/86	1986/87	MEAN
0+ CRAB					
APRIL-MAY	13.7	35.0	5.0	0.1	13.4
JUNE-SEPT	2.2	138.5	536.7	13.3	172.7
OCT-DEC	(0.9)	(58.2)	(204.0)	(5.0)	(72.5)
JAN-MARCH	(0.4)	(27.5)	(102.0)	(2.5)	(34.3)
1+ CRAB					
APRIL-MAY	2.9	2.7	11.5	0.5	4.4
JUNE-SEPT	1.1	0.9	39.1	0.7	10.5
OCT-DEC	(0.6)	(0.5)	(22.3)	(0.4)	(6.0)
JAN-MARCH	(0.4)	(0.3)	(14.1)	(0.3)	(3.8)
>1+ CRAB					
APRIL-MAY	0.7	0.2	0.1	2.3	1.4
JUNE-SEPT	1.7	0.8	2.8	2.8	2.0
OCT-DEC	(1.1)	(0.5)	(1.8)	(1.8)	(1.3)
JAN-MARCH	(0.8)	(0.4)	(1.3)	(1.3)	(1.0)
TOTAL					
APRIL-MAY	17.3	37.9	16.6	2.9	19.2
JUNE-SEPT	5.0	140.4	578.6	16.8	185.2
OCT-DEC	(2.6)	(59.2)	(228.1)	(7.2)	(79.8)
JAN-MARCH	(1.6)	(28.2)	(117.4)	(4.1)	(39.1)

Table 4.3 Estimated total local seasonal crab populations, Grays Harbor and adjacent nearshore combined. Data as in Table 4.1.

	GRAYS HARBOR AND NEARSHORE POPULATION (MILLIONS)				
	1983/84	1984/85	1985/86	1986/87	MEAN
0+ CRAB					
APRIL-MAY	174.4	673.3	36.3	7.1	222.8
JUNE-SEPT	24.2	168.3	565.3	27.7	195.4
OCT-DEC	(13.6)	(75.4)	(215.8)	(10.8)	(84.6)
JAN-MARCH	(4.6)	(38.3)	(108.4)	(5.5)	(41.2)
1+ CRAB					
APRIL-MAY	7.9	3.0	17.8	1.7	7.6
JUNE-SEPT	12.9	6.0	44.3	6.0	17.3
OCT-DEC	(5.4)	(3.2)	(26.1)	(3.1)	(9.5)
JAN-MARCH	(0.8)	(1.0)	(16.1)	(1.0)	(4.5)
>1+ CRAB					
APRIL-MAY	3.8	1.2	0.7	3.2	2.8
JUNE-SEPT	3.8	2.3	3.2	4.2	3.4
OCT-DEC	(3.4)	(1.8)	(2.1)	(3.1)	(2.5)
JAN-MARCH	(1.4)	(0.7)	(1.4)	(1.7)	(1.3)
TOTAL					
APRIL-MAY	186.1	677.5	54.8	12.0	233.2
JUNE-SEPT	40.9	176.6	612.8	37.9	216.1
OCT-DEC	(22.4)	(80.4)	(244.0)	(17.0)	(97.9)
JAN-MARCH	(6.8)	(40.0)	(125.9)	(8.2)	(47.0)

Table 4.4 Average seasonal crab densities (crab/ha) for the two Grays Harbor subtidal sampling strata where dredging will occur. Data for fall and winter are projected from summer values, as described in text.

AVERAGE SEASONAL CRAB DENSITIES (number/ha)

	Grays Harbor Bar to South Reach			Crossover Reach to Aberdeen		
	4-yr Mean	1983/84	1984/85	4-yr Mean	1983/84	1984/85
0+ CRAB						
April-May	463	537	1282	2900	24	11539
June-Sept	288	274	794	353	295	991
Oct-Dec	262	118	723	319	767	900
Jan-March	203	90	556	248	110	696
1+ CRAB						
April-May	159	425	3	157	338	33
June-Sept	531	1175	274	176	362	52
Oct-Dec	277	460	142	91	400	29
Jan-March	74	58	38	24	24	10
>1+ CRAB						
April-May	189	405	88	62	76	86
June-Sept	197	290	222	38	81	48
Oct-Dec	173	236	194	33	257	43
Jan-March	47	53	52	10	71	10
TOTAL						
April-May	811	1367	1373	3119	438	11958
June-Sept	1016	1739	1290	567	738	1091
Oct-Dec	712	814	1059	443	1424	972
Jan-March	324	211	646	282	205	716

factors" for each age class, which were calculated by using the trend appropriate to the subpopulation. Table 4.5 summarizes these summer-to-fall and summer-to-winter conversion factors. For 0+ crab in Grays Harbor, the subtidal populations remain much higher than might be expected from natural mortality, which probably reflects movement of 0+ crabs off the intertidal during these months. For older crab, the summer-to-fall subtidal transition is roughly what is expected from mortality alone, but the populations drop considerably during winter. This drop is consistent with a migration out of Grays Harbor (see Section 2.4), but may also reflect a problem with sampling efficiency during this season.

Table 4.5 Summer-to-winter population conversion factors. (See text for explanation.)

	Percentage of summer population remaining in:	
A. Nearshore and Grays Harbor Intertidal		
Age Class	Fall	Winter
0+	38	19
1+	57	36
>1+	65	47
B. Grays Harbor Subtidal		
0+	91	70
1+	52	14
>1+	88	24

4.2.2 Selection of Populations for Analysis

Of the population data presented above (Tables 4.1-4.4) the single most representative series is the four-year mean population. For this reason, results using the mean population have been emphasized in our impact projections (Sections 5.0 and 6.0). However, we also wished to provide some idea of the variations in impact that might result from

variations in the crab population. Given the simplicity of the model used here, and the short time series of data available, statistical estimates of this variation were clearly beyond our scope. For this reason, we chose to select from the data set the two specific years that would be most likely to result in the lowest and highest projected crab losses: in essence, a "best" and a "worst" case. From initial calculations, it was obvious that the 0+ age class was not important in the entrainment calculation, largely because the bulk of 0+ crab are in the intertidal or nearshore areas, not in the estuary subtidal where dredging would occur. Thus, we selected years on the basis of abundance of 1+ and older crab in the estuary subtidal (Table 4.1). The 1984-1985 sampling season showed the lowest levels of 1+ and older crab in the areas to be dredged, so we designated it as the "best" population level in the sense that fewest crab would be entrained and killed. Similarly, we designated the 1983-1984 sampling data as the "worst" population.

4.2.3 Entrainment Relative to Crab Density

Three main factors determine the number of crab entrained during a dredging operation: 1) the amount of material removed, 2) the type of gear being used, and 3) the local abundance of crab. A series of crab entrainment studies conducted in Grays Harbor (Stevens 1981; Armstrong et al. 1982; McGraw et al. 1987), primarily for hopper-type suction dredges, have given a good sense of the variability in numbers of crab entrained (see Section 3.0). Other studies to date, however, have provided few entrainment rate observations that can be related directly to reliable measurements of crab densities. The 1985 and 1986 entrainment studies (Dinnel et al. 1986a,b; McGraw et al. 1987) are the best in this regard, providing multiple-trawl density estimates directly corresponding to

dredging sites and dates. Armstrong et al. (1982) provided density data to compare with entrainment observations, but these estimated densities are from single (sometimes two) trawls in the general vicinity of the dredging, at times up to two weeks from the date of dredging. Since crab densities vary considerably over short distances, these latter data do not provide reliable estimates of abundances at the dredging sites themselves.

For these reasons, we have used only data for a hopper dredge from the October 1985 and August 1986 studies (Dinnel et al. 1986a,b; McGraw et al. 1987) to determine a relationship between volume of material dredged and local crab abundance. A priori, it was clear that such a relationship should have two characteristics: 1) the number of crabs entrained should generally increase as crab abundance increases, and 2) entrainment should be zero when abundance is zero. Initially, we thought a straight line relationship would be appropriate. However, the few data available suggested a curved relationship. Figure 4.2 shows the available data, with both a straight line and curved line fit by least-square regression (using the STATGRAPHICS nonlinear regression routine) of entrainment rate on estimated crab density (data from Armstrong et al. 1982 are included for comparison only; they were not used in estimation). Table 4.6 provides the two relationships, along with statistical results.

The choice between these two relationships is not clear. The curved function clearly provides a better fit to the five data points. Also, it is obvious that, over all but the highest crab densities in Grays Harbor (Table 4.4), the linear function predicts higher entrainment rates than the curved function. However, consideration should also be given to a few process problems related to these functions:

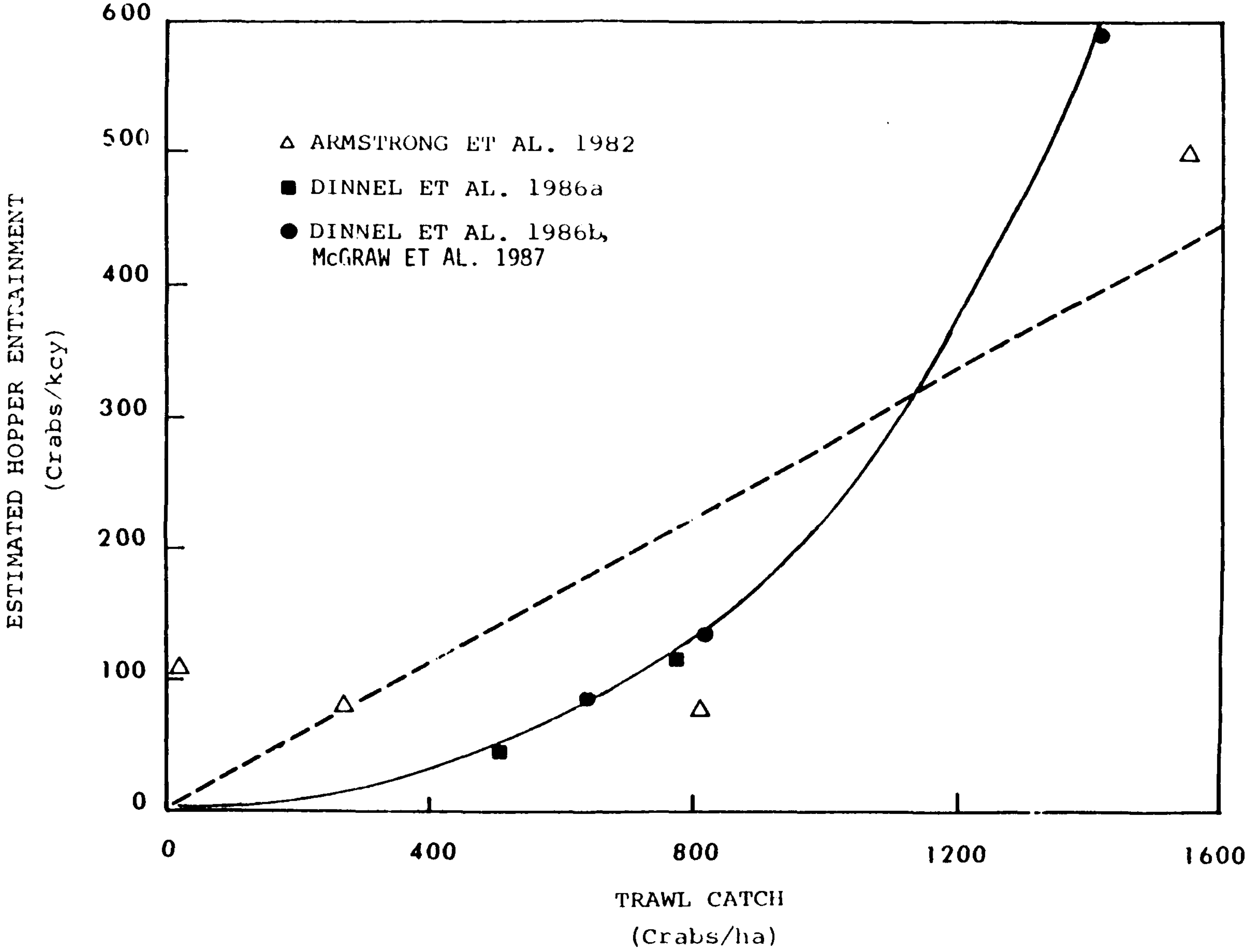


Figure 4.2. Two options for regression of dredge entrainment rates on density. Only the five solid points were used because they are results of studies specifically designed to define such a relationship (see Section 4.0 for details). Data are in Table 3.2.

1) For both functions, the parameter values are largely determined by a single upper sample point.

2) These relationships were estimated over a limited range of crab densities. When densities go beyond this range (as is common in the spring), the linear function predicts moderate increases in entrainment, and the curved function predicts extreme (perhaps unrealistic) increases.

3) The curved function will underestimate entrainment rates for density data that have been averaged over space and time, even if the function accurately reflects underlying processes. This results from a statistical property of all nonlinear functions: the mean of the function evaluated at several values of a variable is not equal to the function evaluated at the mean of the values. For example, imagine that dredging takes place at three different times, when crab densities are 400, 800, and 1200 crab/ha, with a mean density of 800 crab/ha. The curved function predicts entrainment rates of 28.0, 148.8, and 395.3 crab/cy, respectively, with a mean entrainment rate of 190.7 crab/cy. However, the predicted entrainment rate for the mean density (148.8 crab/cy) is 22% lower than this. For the four-year mean data, this could be a substantial effect.

For these reasons, we believe the linear function may be more reliable, but have included both in the results (Sections 5.0 and 6.0). Clearly, further research to better define the nature of the relationsip between entrainment and crab density would be of great value.

These two relationships are used to determine entrainment rates for a hopper dredge for any total (all ages combined) local crab density. Rates for pipeline and clamshell dredges are determined from these relationships

by relative factors given by Stevens (1981): 1) pipeline entrainment is 100% of hopper entrainment, and 2) clamshell is 5% of hopper entrainment. (COE staff have suggested that, based on operational considerations, pipeline entrainment should be only about one-third that of the hopper dredge; this is considered in Section 5.3.)

Table 4.6. Relationship of entrainment to crab density

E = Estimated entrainment rate (crab/1000 cy)
D = Estimated crab density (crab/ha)
SE = Standard error

A. Linear relationship:

$E = a \times D$
$a = 0.285$ $\quad$ $SE(a) = 0.196$

95% confidence interval for a: 0.285 +/- 0.544
$R^2 = 0.630$

B. Curved relationship:

$E = a \times D^b$
$a = 1.5 \times 10^{-5}$ $\quad$ $SE(a) = 1.3 \times 10^{-5}$

$b = 2.41$ $\quad$ $SE(b) = 0.11$
$R^2 = 0.998$

4.2.4 Dredge Mortality

The dredge mortality rates used have already been discussed (Section 3.3). For a hopper dredge, they range from 5% to 86% of those entrained, depending on size (Table 3.3). For a pipeline dredge with confined disposal, mortality is a constant 100%, and it is 10% for a clamshell dredge.

4.2.5 Loss Relative to Age 2+

One of the objectives of this study is to predict loss of crab to the local fishery resulting from the dredging program. Given natural mortality rates, and knowing the age(s) at which crab enter the fishery, this would be a matter of taking calculated loss for a given age class in a given season and multiplying that loss by the proportion of that age class expected to reach the fishery. Unfortunately, there have been few studies of crab mortality, and our analyses of the Grays Harbor and nearshore data (Section 2.5) give reasonably reliable mortality rates only up to the 2+ age class. It is, however, important to have the predicted entrainment loss for the three age classes in different seasons presented on a comparable basis. For these reasons, we have presented the main results of our calculations (Section 5.0) on an age 2+ basis. Further approaches to estimating fishery loss are discussed in Section 6.0.

To convert loss for a given age class in a given season to the number of age 2+ crab that the loss represents, we multiplied the predicted loss of crabs in that age class by the expected natural survival (Section 2.5) to the winter of their third year of life (age class 2+). This results in an estimate that represents the number of those crabs lost that would otherwise have survived to the winter of their 2+ year. Details of the calculation are given in Appendix C.

4.2.6 Dredging Schedule

All runs of the model contained in this report reflect the actual schedule of project operation over two years as now predicted by COE for Widening and Deepening (W&D) (J. Waller, COE, personal communication). The present schedule reflects efforts to mitigate crab loss that were made on the basis of preliminary results from this model. The schedule is

contained in the detailed output of the model given in Appendix B, which shows the years of operation, reaches to be dredged within season, the volume of sediment to be dredged, and type of gear employed. To the extent that the schedule is altered in the future (perhaps to further attenuate loss of crab), the number of crab entrained and killed will also change. At this time, operations for W&D are scheduled to commence in January 1988 (Year 1) and include during that year portions or all of South, Hoquiam, and Crossover Reaches dredged by hopper and clamshell equipment (see Appendix Figures A1-A3). Beginning October 1988 (new fiscal year; Year 2 of W&D) and through September 1989, all other reaches will be dredged.

4.3 Assumptions

In the foregoing discussion several assumptions have been mentioned or implied. In this section we review the major assumptions made and the ways in which they might influence our results.

Considering population estimates first, one major assumption is that trawl density estimates accurately reflect true population density (i.e., trawl efficiency is 100%). Trawl efficiency is undoubtedly somewhat less than this, but we have no estimates of the difference. Since entrainment rates have been calibrated against trawl density estimates, this does not affect estimates of total numbers entrained, but, insofar as total population estimates are low, entrainment as a percentage of local population will be somewhat overestimated.

Two assumptions are involved in relating crab density to entrainment. The process of dredging a section of channel occurs as a series of cuts (usually separated by about one hour) made over several days or weeks, but our measurements of entrainment rate versus density are from very short periods of time. To apply these data to an extended-time project, we have had to assume that crab entrained are immediately replaced by crab from

nearby areas. To the extent that this assumption does not hold, our entrainment estimates are high. We have also had to assume that densities in the channel reaches being dredged are equal to the estimated mean density for the subtidal sampling in the stratum nearest the reach. A few observations have suggested that densities in certain reaches may be higher or lower than the stratum average, so calculated entrainment rates for individual reaches may be low or high (e.g., Dinnel et al. 1986a,b).

A final assumption is that our estimates of certain rates (natural mortality, entrainment, and dredge mortality) accurately reflect "true" rates that will occur during the project. Insofar as these estimates are high or low, entrainment estimates may also be high or low. Table 4.7 presents a summary of these assumptions and their influences on results.

The overall effect of these assumptions cannot be evaluated from our present knowledge of the system because we have made no evaluations of the magnitude of errors associated with these assumptions. Further research (such as calibration of trawl efficiency, further refinement of entrainment rate estimates, or better evaluation of natural mortality) could substantially reduce the uncertainties associated with these assumptions. At present, we can only recommend that these assumptions be considered when evaluating the results of our calculations.

Table 4.7 Summary of major assumptions

Major Assumptions:

+, Assumption tends to overestimate loss
-, Assumption tends to underestimate loss
o, No effect on loss estimate

Assumption	Effect of Fishery Loss Estimate: As number killed	As % of population
1. Trawl efficiency 100%	o	+
2. Entrained crab immediately replaced	+	+
3. Crab density in reach same as stratum mean	+/-	+/-
4. Rate estimates:		
a. Natural mortality		
If low	+	o
If high	-	o
b. Entrainment rate		
If low	-	-
If high	+	+

5.0 CALCULATION OF CRAB ENTRAINMENT AND LOSS

The results of the model presented in this section are based on population abundance estimated in Grays Harbor during the years 1983 through 1986 (see Section 2.0). The various reaches of the navigation channel that will be widened and deepened roughly correspond to the Outer Harbor and Inner Harbor, which are Strata 1 and 3 in the Sea Grant sampling program (Gunderson et al. 1985). Results are based principally on the four-year mean population densities in these strata, but results are also presented on the basis of densities during the "worst" (1983-1984 sampling) and "best" (1984-1985 sampling) years in the data set. The terms "best" and "worst" refer to those population levels that were expected to result respectively in the lowest and highest crab losses (see Section 4.2.2). Loss of crabs due to entrainment is presented in two formats: 1) immediate loss, which is the actual number of crab in a given age class entrained and killed; and 2) relative loss at age 2+, which is the immediate loss multiplied by the expected natural survival of those crabs to age 2+ (see Section 4.2.5 and Appendix C). Loss within any particular reach for any age class due to each piece of gear is then portrayed as a percentage of the total "local area population" for that age class. ("Local area" refers to the combined areas of the Grays Harbor subtidal and intertidal, plus the nearshore area defined in Fig. 2.15.) The local area populations used are those given in Table 4.3. These percentages were calculated for each age class in each season, and then summed across seasons to give an approximate annual percentage.

5.1 Contrast of Gear (for Scheduling Purposes)

In order to determine how the dredging schedule might best be planned to minimize entrainment and mortality of crab, the model was run using the mean population for each of the three gear types separately in all seasons

Table 5.1. Immediate loss rates (crab per 1000 cy dredged) for each type of gear in all reaches of the Outer Harbor (Bar through South Reach) and in all seasons, on the basis of the curved and linear entrainment functions applied to the "mean" population.

Curved Entrainment Function

	HOPPER	PIPELINE	CLAMSHELL
0+ CRAB			
April-May	4.4	87.7	0.4
June-Sept	7.5	74.9	0.4
Oct-Dec	8.3	41.5	0.2
Jan-March	4.2	10.5	0.1
1+ CRAB			
April-May	18.1	30.1	0.2
June-Sept	83.1	138.5	0.7
Oct-Dec	37.6	43.7	0.2
Jan-March	3.2	3.8	0.0
>1+ CRAB			
April-May	30.8	35.8	0.2
June-Sept	44.2	51.4	0.3
Oct-Dec	23.4	27.2	0.1
Jan-March	2.1	2.4	0.0

Linear Entrainment Function

	HOPPER	PIPELINE	CLAMSHELL
0+ CRAB			
April-May	6.6	131.9	0.7
June-Sept	8.2	82.0	0.4
Oct-Dec	15.0	74.9	0.4
Jan-March	23.1	57.8	0.3
1+ CRAB			
April-May	27.2	45.3	0.2
June-Sept	90.9	151.4	0.8
Oct-Dec	67.8	78.8	0.4
Jan-March	18.1	21.1	0.1
>1+ CRAB			
April-May	46.3	53.9	0.3
June-Sept	48.3	56.2	0.3
Oct-Dec	42.3	49.2	0.2
Jan-March	11.4	13.3	0.1

Table 5.2. Immediate loss rates (crab per 1000 cy dredged) for each type of gear in all reaches of the Inner Harbor (Crossover Reach through Aberdeen) and in all seasons, on the basis of the curved and linear entrainment functions applied to the "mean" population.

Curved Entrainment Function

	HOPPER	PIPELINE	CLAMSHELL
0+ CRAB			
April-May	183.2	3663.1	18.3
June-Sept	4.0	40.3	0.2
Oct-Dec	5.2	25.8	0.1
Jan-March	4.2	10.5	0.1
1+ CRAB			
April-May	119.3	198.8	1.0
June-Sept	12.1	20.1	0.1
Oct-Dec	6.3	7.3	0.0
Jan-March	0.9	1.0	0.0
>1+ CRAB			
April-May	67.4	78.3	0.4
June-Sept	3.7	4.4	0.0
Oct-Dec	2.3	2.7	0.0
Jan-March	0.3	0.4	0.0

Linear Entrainment Function

	HOPPER	PIPELINE	CLAMSHELL
0+ CRAB			
April-May	41.3	825.5	4.1
June-Sept	10.0	100.5	0.5
Oct-Dec	18.2	91.0	0.5
Jan-March	28.2	70.6	0.4
1+ CRAB			
April-May	26.9	44.8	0.2
June-Sept	30.1	50.2	0.3
Oct-Dec	22.1	25.8	0.1
Jan-March	5.8	6.8	0.0
>1+ CRAB			
April-May	15.2	17.6	0.0
June-Sept	9.3	10.9	0.0
Oct-Dec	8.2	9.5	0.0
Jan-March	2.3	2.7	0.0

and in all reaches, and immediate loss rate was calculated as crab killed per thousand cubic yards dredged. The results are shown in Tables 5.1 and 5.2, which combine mortality over the series of reaches corresponding to the Outer Harbor and Inner Harbor, respectively (i.e., Bar Reach through South Reach and Crossover Reach through Aberdeen Reach). Results are also given on the basis of the curved and linear entrainment functions described in Section 4.2.3.

In the Outer Harbor, the linear model usually gives higher rates of loss than the curved model for all age classes, because population densities (Table 4.4) are in a range for which the linear model predicts higher entrainment rates (see Fig. 4.2) and possibly because the curved function may be biased low for the mean data (see Section 4.2.3). The greatest mortality is caused by the pipeline dredge for crab in the 0+ age category. Mortality occurs at the highest rate in spring (132 crab/1000 cy dredged) but continues at relatively high rates through all seasons of the year. For 1+ crab, the highest pipeline mortality occurs in summer, reflecting higher resident populations after the spring immigration. Estimated rates of loss between the pipeline and hopper dredge are most disparate for 0+ crab and least for crab >1+ in all seasons because hopper mortality increases with crab age (Table 3.3). In the case of both entrainment functions, the clamshell dredge causes very low loss rates, typically less than 1% of the pipeline figure.

In the Inner Harbor, the calculated rate of loss in spring is two to four times higher for the curved entrainment function than is predicted by the linear model (Table 5.2). This is a result of the extremely high spring crab densities here (Table 4.4). The pipeline dredge again causes higher loss rates than does the hopper dredge, and this discrepancy is most

apparent for 0+ crab and in spring, as is obvious from the mortality rates in Table 3.3. In all seasons other than spring, the linear entrainment function predicts higher rates of mortality for 1+ and >1+ crab than does the curved entrainment function.

These results can provide a basis for modifying the dredging plan to reduce crab loss. It should be noted that, in terms of loss to the crab fishery, 0+ crab are of much less importance than 1+ and older crab. This is because there are few 0+ crab in the areas being dredged as compared to their abundances in the intertidal and nearshore areas, and because the magnitude of natural mortality of this age class is so high (see Section 2.5.2). Thus, for the Outer Harbor (Bar Reach to South Reach), the worst season to dredge is June to September, when older crabs are concentrated in this area (Table 5.1). For the Inner Harbor (Crossover Reach to Aberdeen Reach), the worst season is April and May (Table 5.2). Combining this information with other aspects of crab biology (such as migrations, Section 2.4) and with operational constraints, it may be possible to further refine the dredging schedules to minimize crab loss.

5.2 Loss According to the Dredge Schedule

The dredging schedules discussed in Section 4.2.6 and presented in Appendix B were used to predict entrainment, immediate loss, and relative loss to age 2+ in each of the two years of project construction. Estimates were made for three age classes with both the linear and curved entrainment functions. (Detailed results of these analyses are given in the numerous tables of Appendix B.)

In this section results are summarized and presented for two dredging schedules (without and with confined disposal). Only immediate loss and relative loss at age 2+ are given here. The reader is referred to Appendix B for specific results concerning entrainment per se.

5.2.1 Loss Without Confined Disposal

This construction option uses only the hopper and clamshell dredges for the entire W&D project with the exception of a small portion excavated with a pipeline dredge at Cow Point (374,000 cy of gravel; see Appendices A and B). Compared to the second plan (Section 5.2.2), crab loss is less severe because the mortality of crab entrained by the pipeline is 100% (the highest of all three dredge types) and a substantial amount of pipeline dredging is specified in the second option.

Immediate loss. Effects of construction without confined disposal vary tremendously depending on age class of crab entrained, the entrainment function used (curved or linear), and the population level (mean, best, or worst). In almost every case the loss is greatest in the second year of construction because of extensive work in the Outer Harbor (especially on the bar) where population levels of 1+ and >1+ crab tend to be relatively high compared to the Inner Harbor. For example, losses of 1+ crab based on a mean population value and the linear entrainment function are 328,000 in Year 2 of construction and only 92,000 in Year 1 (Table 5.3). Similarly, immediate loss of crab >1+ (for the most part 2+ age class) are about twice as high in Year 2 at 175,000 compared to 81,000 in Year 1. These high Year 2 losses are largely due to dredging of the bar during the summer of Year 2 (Appendix Table B3b). Comparing losses throughout the entire project for the three population levels, the total loss of 1+ according to the linear model is about 420,000 crab for the "mean" population but more than twice as high, at approximately 1 million crab, for the "worst" population (Table 5.3). The difference is much more pronounced with the curved entrainment function, which predicts a loss of about 295,000 1+ crab from the mean population and over 1.6 million from the "worst" population (Table 5.3).

Table 5.3. Model calculations of Immediate Loss and Relative Loss at age 2+ of crab (thousands) according to the plan *without* confined disposal. Data are summarized from detailed output by season and gear contained in Appendix B. Shown are project losses in years 1 and 2 of actual W & D construction, by age class for three populations levels. Calculations show results using the "curved" and "linear" entrainment functions (Section 4.2.3). Percentage loss (%) is expressed on the basis of total local area population for each age class, as described in Section 5.0 and Appendix C.

IMMEDIATE LOSS (THOUSANDS)

	AGE	YEAR 1		YEAR 2		PROJECT TOTAL	
POPULATION	CLASS	CURVED (%)	LINEAR (%)	CURVED (%)	LINEAR (%)	CURVED	LINEAR
	0+	19 (0.1)	35 (0.4)	301 (2.1)	218 (1.8)	320	252
WORST	1+	153 (2.0)	169 (4.5)	1489 (15.7)	840 (10.4)	1642	1008
(1983)	>1+	170 (4.6)	159 (5.3)	669 (18.4)	418 (12.9)	837	577
	0+	472 (0.2)	170 (0.3)	339 (0.5)	408 (0.7)	810	578
BEST	1+	19 (1.0)	26 (1.7)	185 (3.6)	153 (3.1)	204	178
(1984)	>1+	59 (5.0)	58 (5.5)	229 (11.0)	189 (9.3)	288	247
	0+	30 (0.0)	60 (0.1)	50 (0.0)	145 (0.2)	80	205
MEAN	1+	39 (0.5)	92 (1.2)	256 (1.6)	328 (2.4)	295	420
	>1+	43 (1.7)	81 (3.7)	140 (4.3)	175 (5.7)	183	256

RELATIVE LOSS AT AGE 2+ (THOUSANDS)

	AGE	YEAR 1		YEAR 2		PROJECT TOTAL	
POPULATION	CLASS	CURVED (%)	LINEAR (%)	CURVED (%)	LINEAR (%)	CURVED	LINEAR
	0+	0 (0.1)	1 (0.4)	4 (2.1)	3 (1.8)	4	3
WORST	1+	9 (2.0)	15 (4.5)	143 (15.7)	84 (10.4)	152	99
(1983)	>1+	57 (4.6)	71 (5.3)	363 (18.4)	245 (12.9)	420	316
					Project Total:	576	418
	0+	3 (0.2)	3 (0.3)	5 (0.5)	7 (0.7)	8	10
BEST	1+	3 (1.0)	4 (1.7)	16 (3.5)	14 (3.1)	19	18
(1984)	>1+	28 (5.0)	35 (5.5)	112 (11.0)	96 (9.3)	140	131
					Project Total:	167	159
	0+	0 (0.0)	1 (0.1)	1 (0.0)	2 (0.2)	1	3
MEAN	1+	3 (0.5)	11 (1.2)	22 (1.6)	31 (2.4)	25	42
	>1+	16 (1.7)	40 (3.7)	66 (4.3)	86 (5.7)	82	126
					Project Total:	108	171

Expressed as a percentage of the local area population (as defined in Section 5.0 and Appendix C), the yearly loss of 0+ crab is always low (ranging from 0.1 to 1.8% for the linear entrainment function and from 0.0 to 2.1% for the curved function). This is because most 0+ crab are in either the intertidal or nearshore areas, away from dredging activity, and 0+ crab suffer the lowest dredge mortality rates (Table 3.3). For older age classes (1+ and >1+), the yearly percentages are typically higher, ranging from 1.2% to 12.9% (linear entrainment) or from 0.5% to 18.4% (curved entrainment function). These crab are more heavily concentrated near the dredging activity.

Relative loss at age 2+. Under the construction plan without confined disposal, the relative loss of 0+ crab converted to age 2+ is small because of the substantial natural mortality during the two years between the 0+ and 2+ age classes (Section 2.5). The total project loss (Years 1 and 2 combined) of 0+ crab relative to age 2+ is less than 2% of the entire loss of all three age classes combined for the mean population results (Table 5.3). Loss of 0+ crab as a percentage of total loss reaches 5% or 6% under the "best" population scenario. On an age 2+ basis, most of the total project loss results from entrainment of >1+ crab. This age class accounts for between 73% and 84% of total project losses. The reasons for such a high proportion is that crab in this age class are concentrated in the dredging area and, suffer the highest hopper-dredge mortality rates (Table 3.3) and are reduced least by natural mortality since they are closer to age 2+ than 0+ or 1+ crab. Relative loss for each age class converted to age 2+ is shown in Figure 5.1, which highlights both the relative contribution of each age class to the total project losses and the greater loss predicted by the linear entrainment function.

Project totals. For the total W&D project (all age classes and both construction years combined) without confined disposal, the model with the linear entrainment function predicts that the equivalent of 171,000 to 418,000 age 2+ crab will be lost; with the curved entrainment function, the model predicts that 108,000 to 576,000 age 2+ crab will be lost.

5.2.2 Loss With Confined Disposal

For almost every combination of population scenario, age class, and year of construction, losses under the plan with confined disposal are higher than under the other plan because of the increased use of the pipeline dredge and higher resultant mortality. However, such differences are not always as great as might be expected when total project losses are compared. For instance, losses relative to age 2+ are 202,000 and 171,000 for confined and nonconfined disposal, respectively, based on the mean population and linear entrainment (Tables 5.3 and 5.4).

Immediate loss. For the three age classes under consideration, the greatest increase in loss occurs for 0+ crab and is typically 200% to 300% higher than under the plan without confined disposal (Table 5.4). For crab in the 1+ and >1+ age groups, such increases are much smaller and generally range between 2% and 12% higher with confined disposal. The greatest immediate loss on the basis of the mean population occurs for the 1+ age class for both curved and linear entrainment functions, which predict 317,000 or 494,000 age 1+ crabs lost, respectively. When a "worst" population is considered, these numbers increase to about 2 million for the curved function and 1.3 million for the linear function (Table 5.4). The reason for these age class differences is obvious when the dredge mortality rates for hopper and pipeline dredges (Table 3.3) are compared. For 0+

Table 5.4. Model calculations of Immediate Loss and Relative Loss at age 2+ of crab (thousands) according to the plan with confined disposal. Data are as in Table 5.3.

IMMEDIATE LOSS (THOUSANDS)

	AGE	YEAR 1		YEAR 2		PROJECT TOTAL	
POPULATION	CLASS	CURVED (%)	LINEAR (%)	CURVED (%)	LINEAR (%)	CURVED	LINEAR
WORST	0+	40 (0.2)	71 (0.6)	897 (6.5)	642 (5.2)	937	713
(1983)	1+	179 (2.2)	213 (4.9)	1799 (21.5)	1054 (14.9)	1978	1267
	>1+	176 (4.7)	169 (5.6)	867 (24.4)	567 (17.8)	1044	736
BEST	0+	233 (0.2)	279 (0.4)	819 (1.2)	1013 (1.6)	1052	1292
(1984)	1+	24 (1.0)	32 (1.8)	199 (4.0)	170 (3.8)	223	201
	>1+	62 (5.1)	64 (5.8)	250 (12.6)	214 (10.8)	312	277
MEAN	0+	34 (0.0)	100 (0.1)	105 (0.1)	360 (0.5)	138	461
	1+	47 (0.5)	113 (1.4)	270 (1.8)	380 (3.0)	317	494
	>1+	44 (1.7)	86 (3.8)	145 (4.5)	194 (6.6)	190	280

RELATIVE LOSS AT AGE 2+ (THOUSANDS)

	AGE	YEAR 1		YEAR 2		PROJECT TOTAL	
POPULATION	CLASS	CURVED (%)	LINEAR (%)	CURVED (%)	LINEAR (%)	CURVED	LINEAR
WORST	0+	0 (0.2)	1 (0.6)	11 (6.5)	9 (5.2)	12	9
(1983)	1+	11 (2.2)	18 (4.9)	187 (21.5)	115 (14.9)	199	134
	>1+	60 (4.7)	76 (5.6)	506 (24.4)	355 (17.8)	567	431
					Project Total	778	574
BEST	0+	2 (0.2)	4 (0.4)	12 (1.2)	16 (1.6)	14	20
(1984)	1+	3 (1.0)	5 (1.8)	18 (4.0)	17 (3.8)	21	22
	>1+	30 (5.1)	38 (5.8)	127 (12.6)	114 (10.8)	157	151
					Project Total	192	193
MEAN	0+	0 (0.0)	1 (0.1)	1 (0.1)	6 (0.5)	1	7
	1+	4 (0.5)	13 (1.4)	24 (1.8)	39 (3.0)	28	52
	>1+	17 (1.7)	43 (3.8)	69 (4.5)	101 (6.6)	87	143
					Project Total	116	202

crab in spring, hopper dredge mortality is only 5% of that for the pipeline. For >1+ crab, hopper mortality is 86% of that for the pipeline.

Relative loss at age 2+. Compared to the plan without confined disposal, more extensive use of the pipeline dredge increases overall project loss by about 7% to 18% based on a "mean" population, and up to 37% based on a "worst" population (compare project totals for age 2+ equivalent loss for both entrainment functions in Tables 5.3 and 5.4). Yearly losses within each age class as a percentage of the "local area population" are, again, exceedingly low for 0+ crab, less than 1% of the local population under the "mean" population scenario. For crab in the 1+ and >1+ age classes, such losses range from 0.5% to 6.6% of the local population. However, when the "worst" case population is used as a basis for comparison, the yearly percentage loss of 0+ ranges as high as 6.5% of the "local area population," and for 1+ and >1+ crab, from about 2% to 24%.

The high percentages predicted for older crab reflect the nature of crab distribution in the "worst" year (1983-1984 sampling season). The estuarine population of 1+ and >1+ was very high but nearshore populations were quite low. Further, much of the estuarine population of these age classes was distributed in Strata 1 and 3, which are areas where much of the dredge work for W&D is to be done. Results reflect the fact that loss to an age class can be quite high if a large portion of the age class is located in the vicinity of the navigation channel.

Project totals. For the total project with confined disposal, the linear model predicts that the equivalent of 202,000 to 574,000 age 2+ crab will be lost; the curved model predicts such losses to be 116,000 to 778,000 crab.

The overall difference between the project proposals with and without confined disposal for a "mean" population and projected to age 2+ are shown

in Fig. 5.1. Overall, losses were somewhat higher with confined disposal but not dramatically so. More importantly, the loss predicted by the linear entrainment function is substantially greater than predicted by the curved function. Again, this is because most population densities are on the portion of the entrainment curve (Fig. 4.2) where the linear function predicts a higher entrainment rate and the results using the curved function are lower when mean data is used.

Under both plans it is obvious that loss of 0+ crab projected into the future to age 2+ (as well as to a commercial fishery) is very minor compared to loss of 1+ and >1+ crab (Fig. 5.1).

5.3 Effect of Pipeline Entrainment Set at 100% or 33% of Hopper Entrainment Rate

During the Crab Study Panel (1986) meeting in early December, the assumption that the pipeline entrainment rate is equal to 100% of a hopper rate was challenged. Two major differences between these types of dredge were noted: 1) the area swept by the suction head of the pipeline dredge is substantially less than that covered by the hopper dredge per unit of time operated; and 2) the efficiency of entrainment (capture) of crab in the path of the pipeline dredge may be higher than for the hopper. In considering these two features together, it was decided that a more realistic entrainment rate to assign the pipeline might be 33% of the hopper value. However, subsequent mortality would stay at 100% since the pipeline material is being delivered to confined disposal and there is no chance for survival of crab in that situation.

To explore the effect that a change in entrainment rate for the pipeline dredge would have on overall project impact, the model was run using the mean population, both the curved and linear entrainment

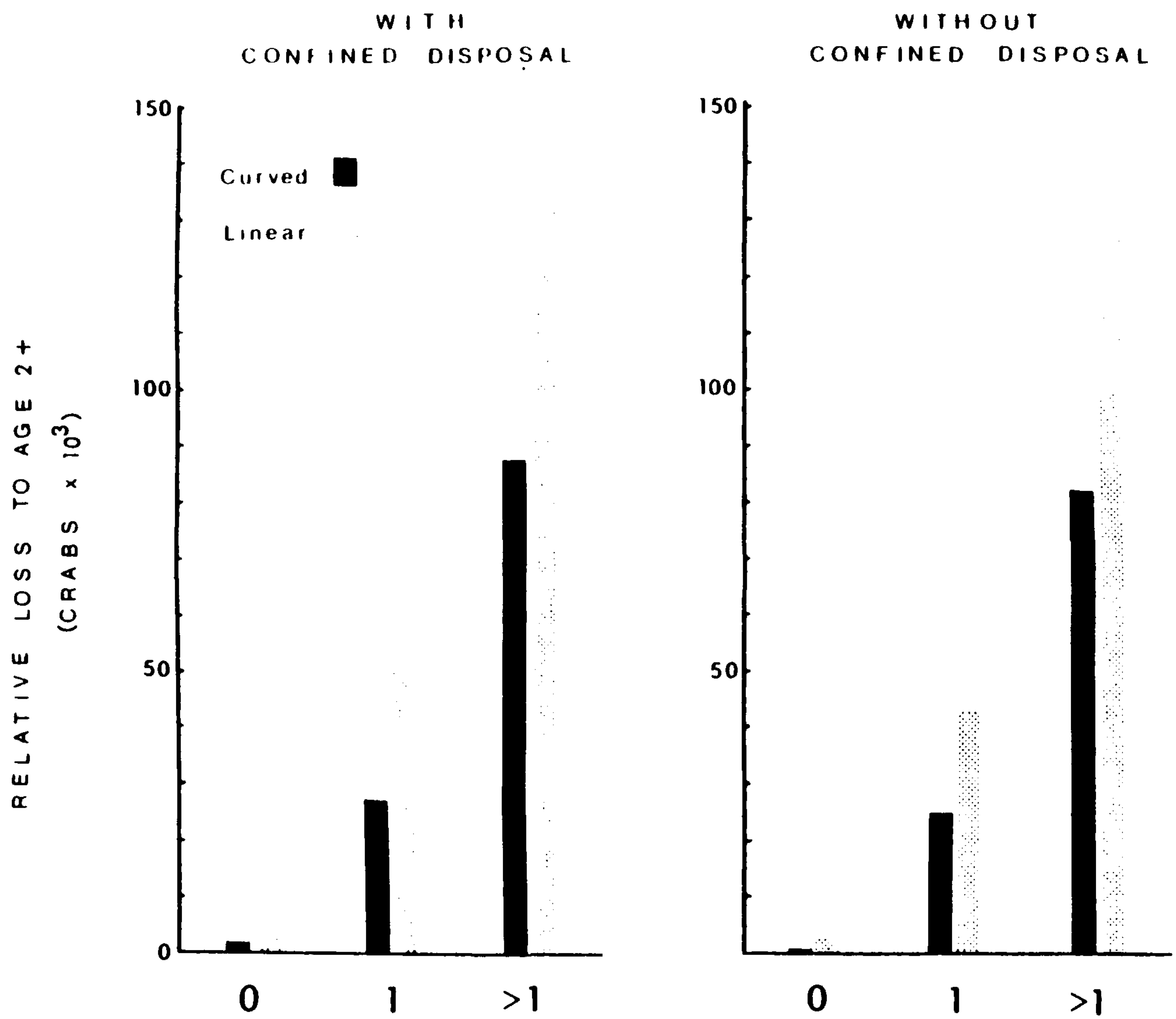


Figure 5.1. Comparison of estimated loss of crab relative to age 2+ by age class according to dredging plans with and without confined disposal as calculated with the curved and linear entrainment functions for the mean population (see Tables 5.3 and 5.4).

functions, and the project schedule with confined disposal. The results (Table 5.5) show total losses relative to age 2+ and, for columns labeled 100% of hopper, are exactly the same as those in Table 5.4 for the mean population. Also shown is the anticipated reduction in overall loss when the entrainment rate for the pipeline is dropped to 33% of that for the hopper. In general, the results are not as dramatic as might be expected. Overall, by reducing pipeline entrainment rates, estimated total project losses are reduced by about 5% (for the curved entrainment function) or 17% (for the linear function). This reduction brings the total project losses for the confined disposal plan down to about the level predicted for the plan without confined disposal (Table 5.3).

Table 5.5 Comparison of Relative Loss to age 2+ when the pipeline entrainment rate is set at either 100% or 33% of the hopper rate, for the plan with confined disposal and based on the "mean" population (refer to Table 5.4). Detailed results are in Appendix B.

RELATIVE LOSS TO AGE 2+(THOUSANDS)

Pipeline Entrainment	100% of Hopper		33% of Hopper	
Entrainment Function	Curved	Linear	Curved	Linear
Year 1				
0+	0	1	0	1
1+	4	13	3	1
>1+	17	43	17	41
Total	21	57	20	43
Year 2				
0+	1	6	1	3
1+	24	39	22	33
>1+	69	101	66	89
Total	95	146	90	125
Project Total	116	202	110	168

6.0 POTENTIAL LOSS TO THE FISHERY

Although the impact model is based on many assumptions, the results predicting loss normalized to age 2+ are relatively straightforward and reflect differences created by the dredging schedule, in different years by different types of gear, and in different reaches of the navigation channel. The step of taking estimated losses of male and female juvenile crab and projecting them as losses of males to a future fishery is predicated on assumptions that reflect a certain amount of ignorance regarding natural mortality rates of larger individuals and mortality caused by the fishery itself. Readers of this report should be cautious in using these projections, although it is expected that they will be used for two purposes: 1) to calculate an absolute number of male crabs lost to a future fishery resulting from immediate losses of all age classes in both years of construction with or without confined disposal; and 2) to approximate the percentage loss from dredging relative to a future fishery.

In the following sections, we take two approaches to approximating loss to the fishery:

1) On the basis of the results presented in Section 5.2, we project losses forward to the fishable population (males larger than 159 mm CW) using growth and survival estimates from Sections 2.2 and 2.5 (Section 6.1).

2) We attempt to put the results from Section 5.2 into the perspective of the Washington coastal crab fishery (Section 6.2).

6.1 Dredging Impact and Loss of Male Crab at Age 3.5 Years (3+)

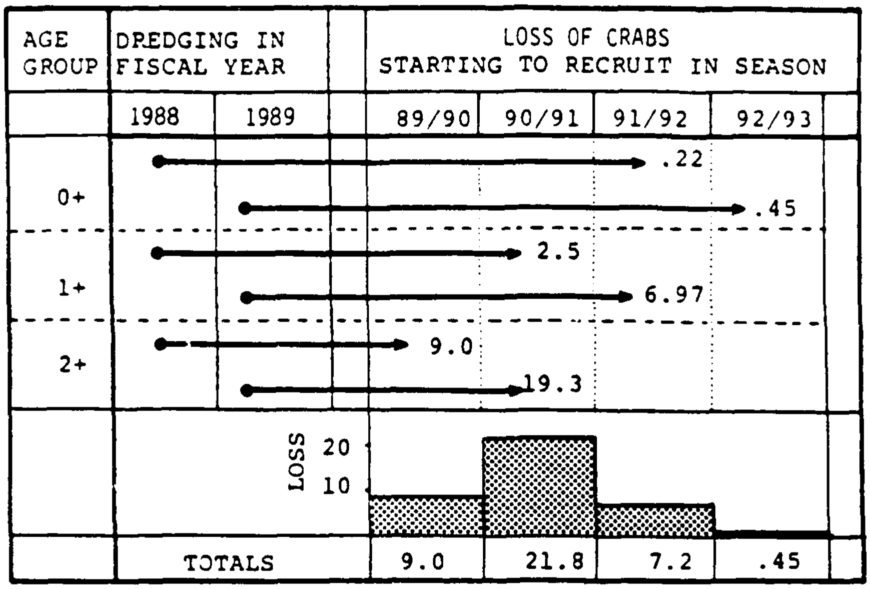
One approach to calculate males theoretically lost to a fishery is to use the data contained in Tables 5.3 and 5.4, which give the loss of each of the three age classes relative to age 2+ crab, and carry this loss 1

more year to age 3.5 (3+) when male crab theoretically begin to enter the fishery. It is first necessary to reduce the values given by 50% since the data in Tables 5.3 and 5.4 are for both sexes combined, and we have assumed a sex ratio of 1:1. For this analysis, we have used the 45% survival rate between ages 2+ and 3+ calculated (after excluding the 1984 year class) in Section 2.5.

Because of the myriad number of combinations of dredge schedule, gear, reaches, construction years, age classes, and plans with and without confined disposal, we have limited the calculations and analyses of potential fishery loss to those results given by the linear entrainment function for the mean population scenario. (The linear function is used for the reasons given in Section 4.2.3.) The reader can follow our procedures to generate similar numbers for the "best" and "worst" population results provided in Tables 5.3 and 5.4.

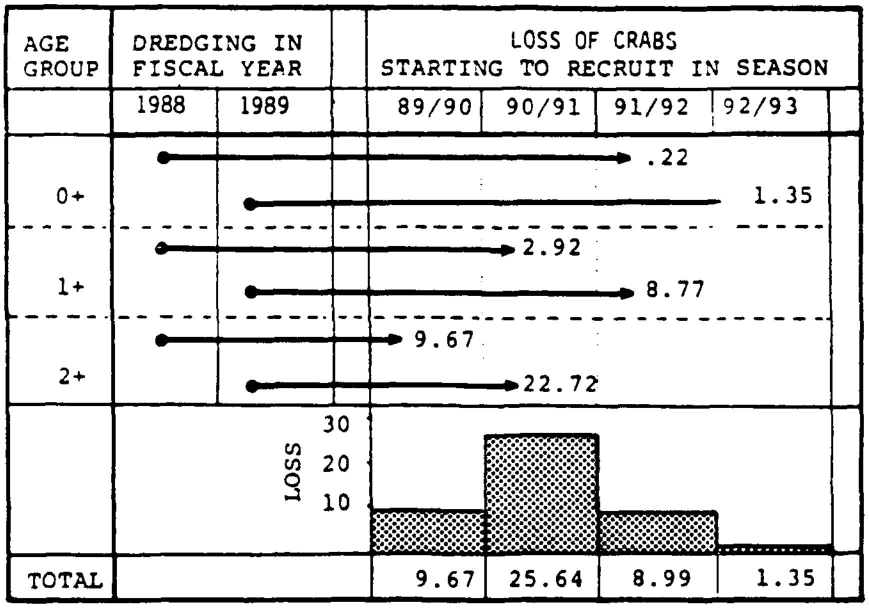
Taking the plan <u>without</u> confined disposal as a first example, the total projected relative loss at age 2+ for the entire project, based on the mean population and the linear entrainment function, is 171,000 crab (Table 5.3). Half of this value is about 85,500 crab, which multiplied by survival over the next year (0.45) equals about 38,000 male crab at age 3.5 years that would be lost during both years of dredging operations from all three age classes; this result is shown in Fig. 6.1A. If we assume that male crab enter the fishery at age 3.5 (see discussion in Section 2.2.5), the results can be portrayed in more detail. Shown in Fig. 6.1A are the losses in each of two fiscal dredging years for each of three age groups carried forward to the respective years when they will enter the fishery as 3.5-year-old males. For example, loss of 0+ crab during operations in 1988 (Year 1) will be seen in the commercial fishery that starts in December of 1991, when they are 3.5 years old. Similarly, loss of 0+ crab in

A. WITHOUT CONFINED DISPOSAL.



LOSS FROM DREDGING IN 1988: 11.72
LOSS FROM DREDGING IN 1989: 26.72
TOTAL LOSS: 38.44

B. WITH CONFINED DISPOSAL.



LOSS FROM DREDGING IN 1988: 12.81
LOSS FROM DREDGING IN 1989: 32.84
TOTAL LOSS: 45.65

Figure 6.1. Projection of male crab loss (thousands) to age 3.5 when theoretically available to the fishery. Losses are broken down by age class in two years of construction, and from a particular age carried forward in time by appropriate survival rates until the fishing season when they are age 3.5 years. The histograms show total loss per season. A: without confined disposal; B: with confined disposal. (Calculations are based on projected losses to age 2+ for the linear entrainment function and the "mean" population, Tables 5.3, 5.4).

construction year 1989 (Year 2) will be lost to the fishery beginning with the 1992 season. The resultant numbers reflect survivorship after annual natural mortality rates have been applied from age of impact to entry into the fishery at 3.5 years old. Of the total 38,400 crab theoretically lost to a future fishery because of impact caused by construction without confined disposal, more than half are lost one year after conclusion of the dredging in the 1990-1991 fishing season (Fig. 6.1A).

A similar result is obtained with data based on the construction plan with confined disposal. Of a total of 202,000 crab lost at age 2+ (Table 5.4), 101,000 will be male crab, of which 45,700 survive over the next year to age 3.5 (Fig. 6.1B). Again, from each year of construction, these can be proportioned out according to when each age class would have reached the fishery, and again over half of the predicted loss to the fishery occurs in the 1990-1991 fishing season (Fig. 6.1B).

These figures summarize the average expected losses at the time when recruitment to the fishery begins, but it should be clear that the numbers are not the quantities expected to be lost from the commercial catch for the following reasons:

1. The fishery does not take all of the crabs recruited to legal size, and exact catch rates are not known for the southern Washington coast. In an analysis of California data, Methot and Botsford (1982) reported that exploitation rate, as a percent of the estimated preseason abundance, was not as high as had been assumed elsewhere in the literature. Rather, their estimates vary in accord with abundance, with about 69% of legal males taken in years of high abundance, 84% in the first low abundance year, following a period of high abundance, and about 54% during

other low abundance years (this point is discussed further in Section 6.3 relative to Washington coastal landings).

2. Not all the male crab in a given year class are recruited to the fishery at age 3.5. Anywhere from half to all of a year class may recruit at age 4.5, according to growth schedules of cohorts contained in this report (Section 2.5) and given by Botsford (1984).

The reader should recall that the numbers of 3.5-year-old male crab lost during operations with and without confined disposal (45,700 and 38,400, respectively) are based on the "mean" population only. A rough sense of how much higher these values could be in the context of "worst" population can be obtained by referring again to Tables 5.3 and 5.4. Under the plan without confined disposal the difference in the the total Relative Loss at age 2+ predicted by the linear entrainment function is 171,000 and 418,000 for the "mean" and "worst" populations, respectively; a factor about 2.4 higher for the "worst" population. This differential is about 2.8 for the plan with confined disposal (Table 5.4). These factors could be used in multipliers to increase the predicted crab losses given in Figures 6.1A and 6.1B.

A similar, although computationally simpler, analysis can be made to obtain a rough estimate of percentage loss to the local area fishable population (i.e., the population of legal-sized male crab within Grays Harbor and the nearshore area identified in Fig. 2.15). If we assume, as we did above, that all crab recruit to the fishery at the same age and that natural mortality is constant over time, then the percentages given in Tables 5.3 and 5.4 translate directly into percentages lost to the fishable population. As an example, to estimate the percentage loss to local area fishery recruitment for the 1990-1991 fishing season, we can simply combine

the percentages lost to the age 1+ population during Year 1 of the project with those for age 2+ population during Year 2 (cf. Fig. 6.1). For the plan without confined disposal (Table 5.3), using the mean population and the linear entrainment function, we find 1.2% of the local 1+ crab would be lost in Year 1 and 5.7% of the >1+ (which are almost entirely age 2+) crab would be lost in Year 2, for a total loss to the 1990-1991 local area recruitment of about 6.9%. (This result is not exact because it ignores the fact that crab entrained and killed in one year cannot be killed again the next year, but this error is quite small.) As we have no fishery data corresponding to this local area, such percentages are of questionable value, so we have not presented the full analysis here.

6.2 Dredging Impact as Loss of Male Crab at Age 3.5 Relative to Historical Fishery Landings

It is impossible to determine the relationship between estimates of juvenile crab loss from Grays Harbor estuary and the adjacent nearshore area and landings from the coastal fishery because there are no estimates of the commercial catch for this local area. The average annual landings for the outer coast of Washington has been 3,465,100 lb over the last six fishing seasons (PMFC 1985; Steve Barry, WDF, personal communication). Assuming an average weight of 1.8 lb/crab, this equates to 1.925 million crab. The outer coast can be roughly divided into four broad areas centered around the Columbia River estuary, Willapa Bay, Grays Harbor, and Destruction Island. Data used in our model come from the Grays Harbor area only, and it might be tempting to divide the total average catch by four, which would equate to 81,000 crab.

The results of this approach seem too risky since the proportion of total landings attributable to juveniles originating in or nearshore of

Grays Harbor cannot be determined (and in fact may be much higher than 25% of coastal landings). The approach used instead is to consider the results from Section 6.1 relative to the recent historical level of the Washington State crab fishery.

The purpose of the calculations in this section is to compare the estimates of dredge impact and loss of male crab at 3.5 years of age to recent historical trends in Washington State's commercial fishery. Unlike the previous section, however, here we calculate extremes of possible impact to show how high or low losses might be. Calculations in this section are based on the "best" and "worst" population estimates contained in Tables 5.3 and 5.4. These calculations were made separately for the two entrainment functions (curved and linear). Results are summarized in Tables 6.1 and 6.2. As an example, the following paragraphs describe the steps for the curved entrainment function.

Step 1. To calculate the total loss of male crab to the fishery (Table 6.1A), we began with total project losses equivalent to age 2+ crabs. From Tables 5.3 and 5.4, we selected, for each dredging plan, the highest and lowest predicted losses. For the plan without confined disposal (Table 5.3), the highest and lowest values are 108,000 and 575,000 age 2+ crab; for the plan with confined disposal (Table 5.4), these values are 116,000 and 778,000 age 2+ crab, respectively. These values were first converted to loss at age 3.5 (assumed to be the age of fishery recruitment) by using a survival rate of 45%, and then reduced by 50% to represent males only.

Step 2. In order to calculate actual loss to the fishery from the number of male crab lost to the fishable population, we need to know the fishery exploitation rate (i.e., what portion of available legal crabs are actually caught in any given year). As was mentioned above (Section 6.1),

Table 6.1 Summary of dredging impact as crab loss (males only) at age 3.5 years relative to historical fishery landings, for the curved entrainment function.

	Plan without confined disposal			Plan with confined disposal	
	Lowest Loss	Highest Loss		Lowest Loss	Highest Loss
A. Total Loss to the Fishery					
1) Losses relative to age 2+ (thousands) (x survival to 3+)	108	576	x 0.45 =	116	778
2) Losses relative to age 3+ (thousands) (x proportion of males)	48.6	259.2	x 0.50 =	52.2	350.1
3) Loss of fishable males (thousands) (x exploitation rate)	24.3	129.6	x 0.70 =	26.1	175.0
4) Total loss to the fishery (thousands)	17.0	90.7		18.3	122.5
B. Loss Relative to Historical Landings					
Highest catch (2.61 million crabs)	0.7%	3.5%		0.7%	4.7%
Lowest catch (1.42 million crabs)	1.2%	6.4%		1.3%	8.6%

Table 6.2 Summary of dredging impact as crab loss (males only) at age 3.5 years relative to historical fishery landings, for the linear entrainment function.

	Plan without confined disposal			Plan with confined disposal	
	Lowest Loss	Highest Loss		Lowest Loss	Highest Loss
A. Total Loss to the Fishery					
1) Losses relative to age 2+ (thousands)	159	418		193	574
(x survival to 3+)			x 0.45 =		
2) Losses relative to age 3+ (thousands)	71.6	188.1		88.8	258.3
(x proportion of males)			x 0.50 =		
3) Loss of fishable males (thousands)	35.8	94.0		43.4	129.2
(x exploitation rate)			x 0.70 =		
4) Total loss to the fishery (thousands)	25.0	65.8		30.4	90.4
B. Loss Relative to Historical Landings					
Highest catch (2.61 million crabs)	1.0%	2.5%		1.2%	3.5%
Lowest catch (1.42 million crabs)	1.8%	4.6%		2.1%	6.4%

we do not know exploitation rates for the Washington coast, but Methot and Botsford (1982) estimated exploitation rates for the northern California crab fishery to range from 54% to 84%. For the present, we will assume a rate of 70%, near the midpoint of that range. Then, the actual number of new recruits lost to the fishery can be estimated by multiplying the number lost to the fishable stock by the exploitation rate (Table 6.1A).

Step 3. To express this loss to the fishery as a percentage of total Washington coast crab landings (Table 6.1B), we have used the highest and lowest seasonal landings from the last six fishing seasons: 2.609 million crabs (4.697 million pounds) in the 1983/1984 season, and 1.425 million crabs (2.565 million pounds) in the 1981/1982 season (PMFC 1985). The highest and lowest losses calculated above were divided by the highest and lowest annual catches, to yield a range of percent losses on a coastwide basis. Those percentges range from 0.7% to 6.4% for the plan without confined disposal, and from 0.7% to 8.6% for the plan with the confined disposal (Table 6.1B).

The reader should be advised that these percentages must be viewed with caution. The impact model estimates numbers of juveniles killed, and then males lost to the commercial fishery are calculated by several other steps. All such calculations stem from population survey estimates from the Sea Grant sampling that primarily addressed juvenile crab. Based on the best estimates of natural mortality we have available from our data, and population estimates from "worst" and "best" case scenarios, the resultant estimates of male crab lost to the fishery due to dredging activity seem reasonable. The data on actual range of landings in the commercial fishery for Washington are also straightforward. But the steps by which we have put the two together contain many assumptions,

particularly in that we derive percentages (of loss to the fisehry) on the basis of two sets of estimates derived by completely different methods. It should also be remembered that calculated losses for three age classes are derived for each of two years of construction and summed together. As portrayed in Figs. 6.1A and 6.1B, crabs eventually lost to the commercial fishery will not be lost in one fishing season, but rather over at least three and possibly four fishing seasons. Thus, the annual percentage loss relative to fishery landings will probably be lower than those given in Table 6.1. Furthermore, the range of percentages given in Table 6.1B assumes that crab loss (as a function of Grays Harbor crab abundance) is independent of coastwide crab landings. It is more likely that the abundance of crab in Grays Harbor fluctuates in phase with coastwide abundance, so that high levels of crab entrainment and loss would correspond with high fishery landings, and low crab loss with low landings. Taking this into account, more likely ranges of loss to the coastal fishery (Table 6.1B) would be 1.2% to 3.5% for the plan without confined disposal, and 1.3% to 4.7% for the plan with confined disposal.

Losses relative to the historical fishery based on the linear entrainment function have a narrower range between the lowest and highest calculated percentages (Table 6.2). The greatest losses are 4.6% and 6.4% for plans without and with confined disposal, respectively; both occurring in a year of low catch. Again, it seems most reasonable to assume that entrainment and loss of crab will be in some proportion to population density (i.e. year class strength), within the area. If so, then more likely ranges would be 1.8% to 2.5% and 2.1% to 3.5% for plans without and with confined disposal, respectively.

7.0 RECOMMENDATIONS FOR FURTHER STUDIES AND IMPROVEMENT OF THE IMPACT MODEL

1. Because so much of the impact model depends on the relationship between crab density and entrainment rate (Fig. 4.2) and so few specific data are available on which to construct that model, any additional directed research that will elucidate how entrainment rate changes as a function of crab density would be one of the most important possible improvements to the model.
2. We have assumed a 1:1 sex ratio throughout the model although we know that crab are at times highly aggregated by sex within the estuary. There is, within the Sea Grant data base, the capacity to better define sex ratio in both the Inner and Outer harbors, where widening and deepening is to occur. We suspect that the sex ratio will be in favor of males within the estuary, and thus impacts to the fishery will be higher than those estimated in this report.
3. We believe estimates of natural mortality through age 2+ are fairly good, but overall mortality estimates could be improved by analyzing the data in terms of specific year classes and attempting to learn how catchability changes on a seasonal basis. Natural mortality rates, as can be seen in the model, drive the results to a great extent when immediate loss is carried forward in time to any older age class.
4. Estimates of entrainment within actual years of construction should definitely be made so that calculations are not dependent on average values taken from previous Sea Grant studies. If calculations of crabs entrained and lost during years of construction are necessary to provide for mitigation or compensation, or to render a judgement of (non)significant impact, then acquisition of actual data on both crab

abundance and entrainment during construction should be viewed as a high priority.

5. All the calculations contained in this report relate only to widening and deepening per se, and there has been no attempt to estimate losses during future years from the more extensive maintenance dredging of the expanded channel. Whether or not such future losses are viewed as important is a decision that rests with agencies concerned and commercial crab fishermen, but the means to provide such calculations are certainly contained in the existing model.

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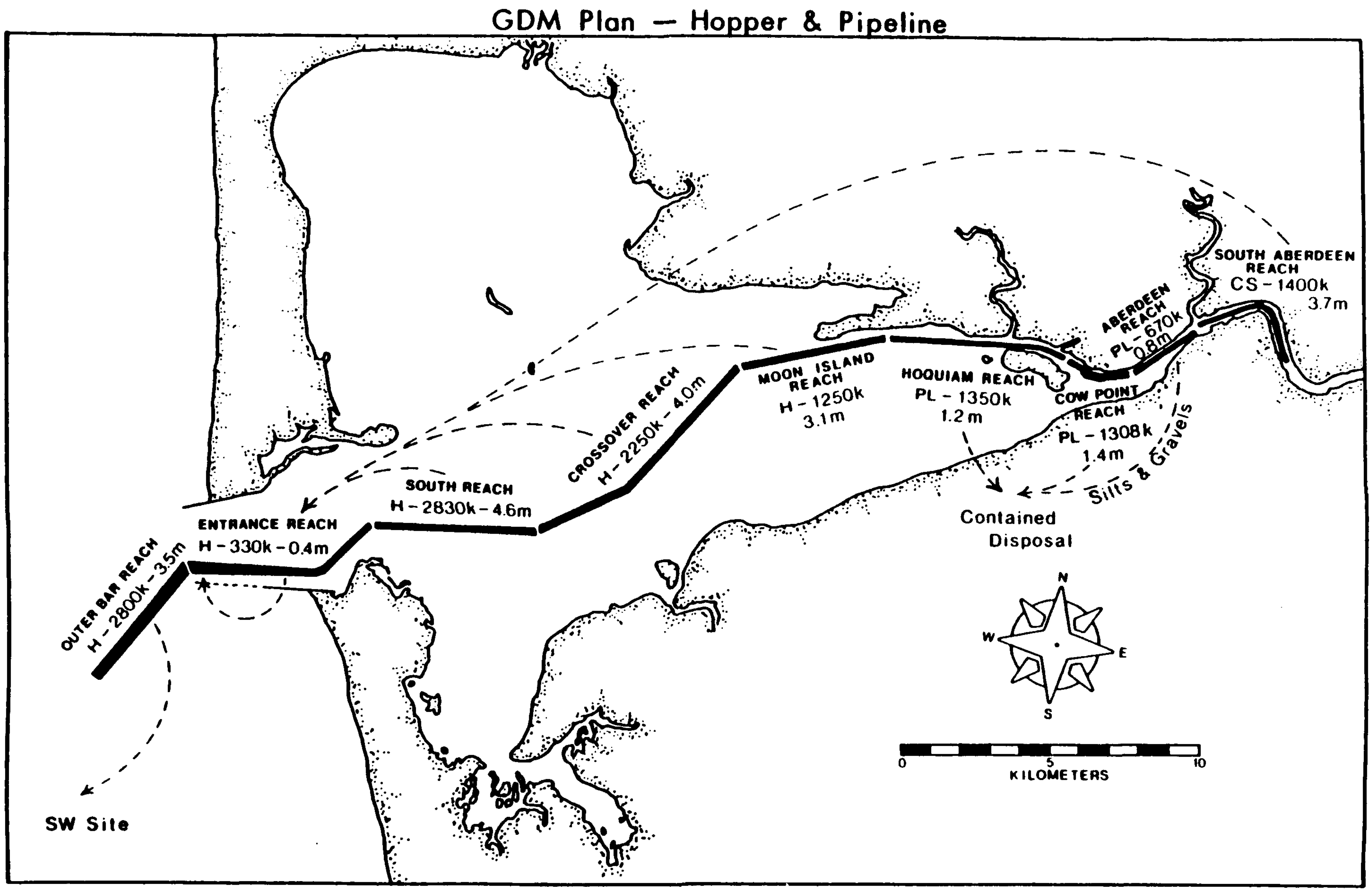
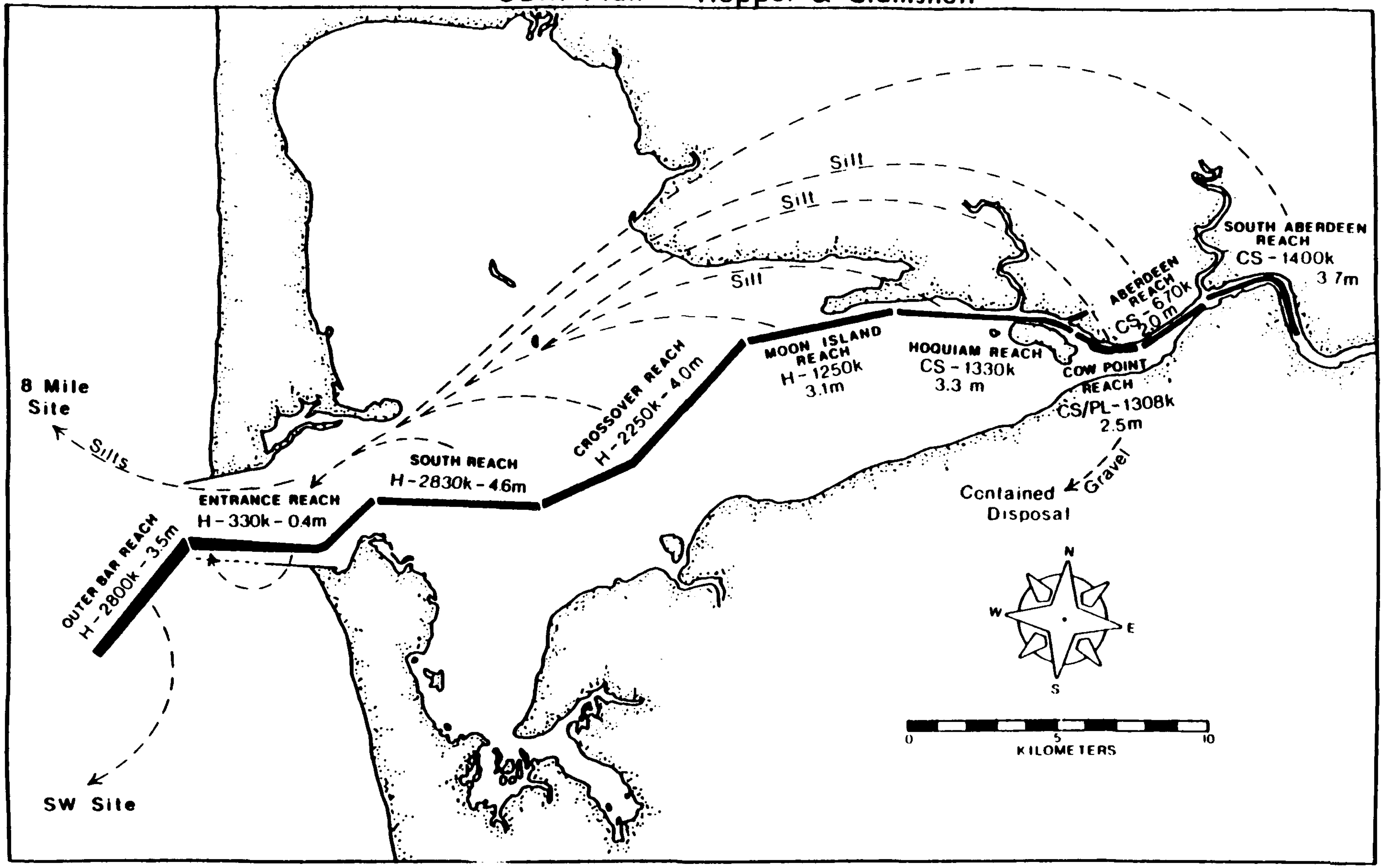
APPENDIX A

DREDGE PLAN



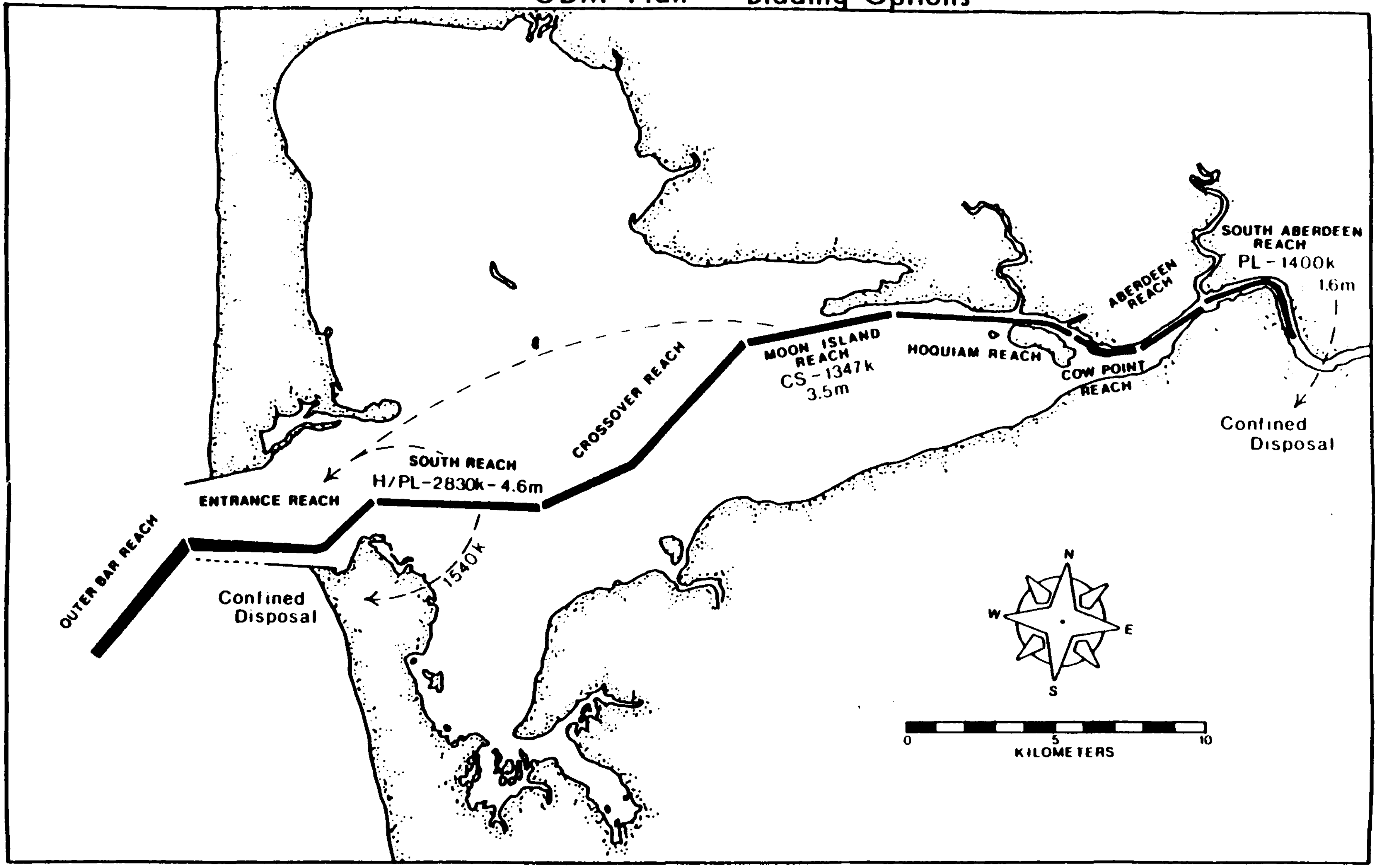
Appendix Figure A1. Diagram of the proposed Grays Harbor widening and deepening dredging plan with confined disposal by pipeline dredge for a portion of the dredged materials. Abbreviations: H = hopper dredge; CS = clamshell dredge; K = 1,000 cy; m = # months required for dredging.

GDM Plan — Hopper & Clamshell



Appendix Figure A2. Diagram of the proposed Grays Harbor widening and deepening dredging plan without confined disposal by pipeline dredge. Abbreviations: H = hopper dredge; PL = pipeline dredge; CS = clamshell dredge; K = 1,000 cy; M = # months required for dredging.

GDM Plan — Bidding Options



Appendix Figure A3. Diagram of proposed bidding options to be considered for inclusion in the Grays Harbor widening and deepening dredging plan. Abbreviations: H = hopper dredge; PL = dredge; CS = clam shell; K = 1,000 cy; M = # months required for dredging.

APPENDIX B

DETAILED RESULTS

LIST OF TABLES

Table B1a: Entrainment (Number of Crabs)
Without Confined Disposal, Linear Entr. Function, Best Population

Year	Season	Reach	Equipment	Vol.	Age Class 0+	1+	>1+
1	Jan-Mar	South	Hopper	1698	269071	18557	25184
				Season Total:	269071	18557	25184
				% of G.H. Population	2.50	2.58	7.20
				% of Local Area Population	0.70	1.78	3.45
1	Apr-May	South	Hopper	1132	413547	884	28277
1	Apr-May	Hoquiam	Clamshell	771	126774	366	942
				Season Total:	540322	1250	29219
				% of G.H. Population	0.08	0.50	2.95
				% of Local Area Population	0.08	0.04	2.46
1	Jun-Sep	Crossover	Hopper	1000	282420	14936	13578
1	Jun-Sep	Hoquiam	Clamshell	579	8176	432	393
				Season Total:	290596	15368	13971
				% of G.H. Population	0.98	0.30	0.95
				% of Local Area Population	0.17	0.25	0.62
				Annual Total:	1099989	35175	68374
2	Oct-Dec	Crossover	Hopper	250	64156	2037	3055
2	Oct-Dec	Moon Is.	Hopper	1786	458327	14550	21825
2	Oct-Dec	Cow pt.Si	Clamshell	778	9983	317	475
2	Oct-Dec	Cow pt.Gr	Pipeline	374	95977	3047	4570
				Season Total:	628442	19951	29926
				% of G.H. Population	3.65	0.75	2.30
				% of Local Area Population	0.83	0.63	1.64
2	Jan-Mar	Crossover	Hopper	1000	198237	2716	2716
2	Jan-Mar	Moon Is.	Hopper	714	141541	1939	1939
2	Jan-Mar	Cow pt.Si	Clamshell	156	1546	21	21
2	Jan-Mar	Aberdeen	Clamshell	670	6641	91	91
				Season Total:	347966	4767	4767
				% of G.H. Population	3.23	0.66	1.36
				% of Local Area Population	0.91	0.46	0.65
2	Apr-May	Entrance	Hopper	330	120557	258	8243
				Season Total:	120557	258	8243
				% of G.H. Population	0.02	0.10	0.83
				% of Local Area Population	0.02	0.01	0.69
2	Jun-Sep	Outer bar	Hopper	2800	633854	218570	177042
				Season Total:	633854	218570	177042
				% of G.H. Population	2.13	4.25	12.04
				% of Local Area Population	0.38	3.62	7.80
				Annual Total:	1730819	243545	219978
				Project Totals	2830808	278720	288351

Table B1b: Immediate Dredge Mortality (Number of Crabs)
Without Confined Disposal, Linear Entr. Function, Best Population

Year	Season	Reach	Equipment	Vol.	Age Class 0+	1+	>1+
1	Jan-Mar	South	Hopper	1698	107628	15959	21658
			Season Total:		107628	15959	21658
			% of G.H. Population		1.00	2.22	6.19
			% of Local Area Population		0.28	1.53	2.97
1	Apr-May	South	Hopper	1132	20677	530	24318
1	Apr-May	Hoquiam	Clamshell	771	12677	37	94
			Season Total:		33355	567	24412
			% of G.H. Population		0.01	0.23	2.47
			% of Local Area Population		0.00	0.02	2.05
1	Jun-Sep	Crossover	Hopper	1000	28242	8961	11677
1	Jun-Sep	Hoquiam	Clamshell	579	818	43	39
			Season Total:		29060	9005	11716
			% of G.H. Population		0.10	0.18	0.80
			% of Local Area Population		0.02	0.15	0.52
2	Oct-Dec	Crossover	Hopper	250	12831	1752	2627
2	Oct-Dec	Moon Is.	Hopper	1786	91665	12513	18770
2	Oct-Dec	Cow pt.Si	Clamshell	778	998	32	48
2	Oct-Dec	Cow pt.Gr	Pipeline	374	95977	3047	4570
			Season Total:		201472	17343	26015
			% of G.H. Population		1.17	0.65	2.00
			% of Local Area Population		0.27	0.55	1.43
2	Jan-Mar	Crossover	Hopper	1000	79295	2335	2335
2	Jan-Mar	Moon Is.	Hopper	714	56617	1667	1667
2	Jan-Mar	Cow pt.Si	Clamshell	156	155	2	2
2	Jan-Mar	Aberdeen	Clamshell	670	664	9	9
			Season Total:		136730	4014	4014
			% of G.H. Population		1.27	0.56	1.15
			% of Local Area Population		0.36	0.39	0.55
2	Apr-May	Entrance	Hopper	330	6028	155	7089
			Season Total:		6028	155	7089
			% of G.H. Population		0.00	0.06	0.72
			% of Local Area Population		0.00	0.01	0.60
2	Jun-Sep	Outer bar	Hopper	2800	63385	131142	152256
			Season Total:		63385	131142	152256
			% of G.H. Population		0.21	2.55	10.36
			% of Local Area Population		0.04	2.17	6.71
			Annual Total:		407615	152654	189374
			Project Totals		577658	178184	247161

Table B1c: Relative Loss at Age 2+ (Number of Crabs)
Without Confined Disposal, Linear Entr. Function, Best Population

Year	Season	Reach	Equipment	Vol.	Age Class 0+	1+	>1+
1	Jan-Mar	South	Hopper	1698	2906	3543	21658
			Season Total:		2906	3543	21658
			% of G.H. Population		1.00	2.22	6.19
			% of Local Area Population		0.28	1.53	2.97
1	Apr-May	South	Hopper	1132	62	27	7709
1	Apr-May	Hoquiam	Clamshell	771	38	2	30
			Season Total:		100	28	7739
			% of G.H. Population		0.01	0.23	2.47
			% of Local Area Population		0.00	0.02	2.05
1	Jun-Sep	Crossover	Hopper	1000	141	735	5441
1	Jun-Sep	Hoquiam	Clamshell	579	4	4	18
			Season Total:		145	738	5460
			% of G.H. Population		0.10	0.18	0.80
			% of Local Area Population		0.02	0.15	0.52
			Annual Total:		3151	4310	34857
2	Oct-Dec	Crossover	Hopper	250	167	250	1879
2	Oct-Dec	Moon Is.	Hopper	1786	1192	1789	13420
2	Oct-Dec	Cow pt.Si	Clamshell	778	13	5	34
2	Oct-Dec	Cow pt.Gr	Pipeline	374	1248	436	3268
			Season Total:		2619	2480	18601
			% of G.H. Population		1.17	0.65	2.00
			% of Local Area Population		0.27	0.55	1.43
2	Jan-Mar	Crossover	Hopper	1000	2141	518	2335
2	Jan-Mar	Moon Is.	Hopper	714	1529	370	1667
2	Jan-Mar	Cow pt.Si	Clamshell	156	4	0	2
2	Jan-Mar	Aberdeen	Clamshell	670	18	2	9
			Season Total:		3692	891	4014
			% of G.H. Population		1.27	0.56	1.15
			% of Local Area Population		0.36	0.39	0.55
2	Apr-May	Entrance	Hopper	330	18	8	2247
			Season Total:		18	8	2247
			% of G.H. Population		0.00	0.06	0.72
			% of Local Area Population		0.00	0.01	0.60
2	Jun-Sep	Outer bar	Hopper	2800	317	10754	70951
			Season Total:		317	10754	70951
			% of G.H. Population		0.21	2.55	10.36
			% of Local Area Population		0.04	2.17	6.71
			Annual Total:		6646	14133	95813
			Project Totals		9797	18442	130670

Table B2a: Entrainment (Number of Crabs)
Without Confined Disposal, Linear Entr. Function, Worst Population

Year	Season	Reach	Equipment	Vol.	Age Class 0+	1+	>1+
1	Jan-Mar	South	Hopper	1698	43741	27835	30486
			Season Total:		43741	27835	30486
			% of G.H. Population		1.06	6.79	4.92
			% of Local Area Population		0.96	3.48	2.16
1	Apr-May	South	Hopper	1132	173195	136965	130780
1	Apr-May	Hoquiam	Clamshell	771	262	3716	837
			Season Total:		173457	140682	131617
			% of G.H. Population		0.11	2.81	4.26
			% of Local Area Population		0.10	1.79	3.45
1	Jun-Sep	Crossover	Hopper	1000	84183	103192	23082
1	Jun-Sep	Hoquiam	Clamshell	579	2437	2987	668
			Season Total:		86620	106179	23751
			% of G.H. Population		0.39	0.90	1.14
			% of Local Area Population		0.36	0.82	0.63
			Annual Total:		303817	274696	185854
2	Oct-Dec	Crossover	Hopper	250	54651	28514	18330
2	Oct-Dec	Moon Is.	Hopper	1786	390427	203701	130951
2	Oct-Dec	Cow pt.Si	Clamshell	778	8504	4437	2852
2	Oct-Dec	Cow pt.Gr	Pipeline	374	81758	42656	27422
			Season Total:		535340	279308	179555
			% of G.H. Population		4.23	5.87	7.77
			% of Local Area Population		3.93	5.19	5.27
2	Jan-Mar	Crossover	Hopper	1000	31229	6789	20367
2	Jan-Mar	Moon Is.	Hopper	714	22298	4847	14542
2	Jan-Mar	Cow pt.Si	Clamshell	156	244	53	159
2	Jan-Mar	Aberdeen	Clamshell	670	1046	227	682
			Season Total:		54817	11917	35750
			% of G.H. Population		1.32	2.91	5.77
			% of Local Area Population		1.20	1.49	2.54
2	Apr-May	Entrance	Hopper	330	50490	39928	38125
			Season Total:		50490	39928	38125
			% of G.H. Population		0.03	0.80	1.23
			% of Local Area Population		0.03	0.51	1.00
2	Jun-Sep	Outer bar	Hopper	2800	218570	937666	231684
			Season Total:		218570	937666	231684
			% of G.H. Population		0.99	7.92	11.09
			% of Local Area Population		0.90	7.26	6.13
			Annual Total:		[illegible]59216	1268819	485114
			Project Totals		1163034	1543515	670968

Table B2b: Immediate Dredge Mortality (Number of Crabs)
Without Confined Disposal, Linear EF, Worst Population

Year	Season	Reach	Equipment	Vol.	Age Class 0+	1+	>1+
1	Jan-Mar	South	Hopper	1698	17496	23938	26218
			Season Total:		17496	23938	26218
			% of G.H. Population		0.42	5.84	4.23
			% of Local Area Population		0.38	2.99	1.86
1	Apr-May	South	Hopper	1132	8660	82179	112471
1	Apr-May	Hoquiam	Clamshell	771	26	372	84
			Season Total:		8686	82551	112555
			% of G.H. Population		0.01	1.65	3.64
			% of Local Area Population		0.00	1.05	2.95
1	Jun-Sep	Crossover	Hopper	1000	8418	61915	19851
1	Jun-Sep	Hoquiam	Clamshell	579	244	299	67
			Season Total:		8662	62214	19918
			% of G.H. Population		0.04	0.53	0.95
			% of Local Area Population		0.04	0.48	0.53
			Annual Total:		34844	168703	158690
2	Oct-Dec	Crossover	Hopper	250	10930	24522	15764
2	Oct-Dec	Moon Is.	Hopper	1786	78085	175183	112618
2	Oct-Dec	Cow pt.Si	Clamshell	778	850	444	285
2	Oct-Dec	Cow pt.Gr	Pipeline	374	81758	42656	27422
			Season Total:		171624	242805	156089
			% of G.H. Population		1.35	5.10	6.76
			% of Local Area Population		1.26	4.51	4.58
2	Jan-Mar	Crossover	Hopper	1000	12492	5838	17515
2	Jan-Mar	Moon Is.	Hopper	714	8919	4169	12506
2	Jan-Mar	Cow pt.Si	Clamshell	156	24	5	16
2	Jan-Mar	Aberdeen	Clamshell	670	105	23	68
			Season Total:		21540	10035	30106
			% of G.H. Population		0.52	2.45	4.86
			% of Local Area Population		0.47	1.25	2.14
2	Apr-May	Entrance	Hopper	330	2524	23957	32787
			Season Total:		2524	23957	32787
			% of G.H. Population		0.00	0.48	1.06
			% of Local Area Population		0.00	0.30	0.86
2	Jun-Sep	Outer bar	Hopper	2800	21857	562600	199249
			Season Total:		21857	562600	199249
			% of G.H. Population		0.10	4.75	9.53
			% of Local Area Population		0.09	4.35	5.27
			Annual Total:		217545	839396	418230
			Project Totals		252389	1008099	576920

Table B2c: Relative Loss at Age 2+ (Number of Crabs)
Without Confined Disposal, Linear Entr. Function, Worst Population

Year	Season	Reach	Equipment	Vol.	Age Class 0+	1+	>1+
1	Jan-Mar	South	Hopper	1698	472	5314	26218
			Season Total:		472	5314	26218
			% of G.H. Population		0.42	5.84	4.23
			% of Local Area Population		0.38	2.99	1.86
1	Apr-May	South	Hopper	1132	26	4109	35653
1	Apr-May	Hoquiam	Clamshell	771	0	19	27
			Season Total:		26	4128	35680
			% of G.H. Population		0.01	1.65	3.64
			% of Local Area Population		0.00	1.05	2.95
1	Jun-Sep	Crossover	Hopper	1000	42	5077	9251
1	Jun-Sep	Hoquiam	Clamshell	579	1	24	31
			Season Total:		43	5102	9282
			% of G.H. Population		0.04	0.53	0.95
			% of Local Area Population		0.04	0.48	0.53
			Annual Total:		542	14543	71179
2	Oct-Dec	Crossover	Hopper	250	142	3507	11271
2	Oct-Dec	Moon Is.	Hopper	1786	1015	25051	80522
2	Oct-Dec	Cow pt.Si	Clamshell	778	11	63	204
2	Oct-Dec	Cow pt.Gr	Pipeline	374	1063	6100	19607
			Season Total:		2231	34721	111603
			% of G.H. Population		1.35	5.10	6.76
			% of Local Area Population		1.26	4.51	4.58
2	Jan-Mar	Crossover	Hopper	1000	337	1296	17515
2	Jan-Mar	Moon Is.	Hopper	714	241	925	12506
2	Jan-Mar	Cow pt.Si	Clamshell	156	1	1	16
2	Jan-Mar	Aberdeen	Clamshell	670	3	5	68
			Season Total:		582	2228	30106
			% of G.H. Population		0.52	2.45	4.86
			% of Local Area Population		0.47	1.25	2.14
2	Apr-May	Entrance	Hopper	330	8	1198	10394
			Season Total:		8	1198	10394
			% of G.H. Population		0.00	0.48	1.06
			% of Local Area Population		0.00	0.30	0.86
2	Jun-Sep	Outer bar	Hopper	2800	109	46133	92850
			Season Total:		109	46133	92850
			% of G.H. Population		0.10	4.75	9.53
			% of Local Area Population		0.09	4.35	5.27
			Annual Total:		2930	84280	244952
			Project Totals		3471	98823	316132

Table B3a: Entrainment (Number of Crabs)
Without Confined Disposal, Linear Entr. Function, Mean Population

Year	Season	Reach	Equipment	Vol.	Age Class 0+	1+	>1+
1	Jan-Mar	South	Hopper	1698	98085	35788	22533
			Season Total:		98085	35788	22533
			% of G.H. Population		1.43	3.73	7.04
			% of Local Area Population		0.24	0.76	1.77
1	Apr-May	South	Hopper	1132	149337	51252	60972
1	Apr-May	Hoquiam	Clamshell	771	31824	1727	680
			Season Total:		181161	52979	61652
			% of G.H. Population		0.09	1.65	4.40
			% of Local Area Population		0.08	0.70	2.20
1	Jun-Sep	Crossover	Hopper	1000	100476	50238	10862
1	Jun-Sep	Hoquiam	Clamshell	579	2909	1454	314
			Season Total:		103385	51693	11177
			% of G.H. Population		0.44	0.75	0.83
			% of Local Area Population		0.05	0.30	0.33
			Annual Total:		382631	140459	95362
2	Oct-Dec	Crossover	Hopper	250	22743	6449	2376
2	Oct-Dec	Moon Is.	Hopper	1786	162476	46075	16975
2	Oct-Dec	Cow pt.Si	Clamshell	778	3539	1004	370
2	Oct-Dec	Cow pt.Gr	Pipeline	374	34023	9648	3555
			Season Total:		222781	63177	23276
			% of G.H. Population		1.85	1.77	1.99
			% of Local Area Population		0.26	0.66	0.94
2	Jan-Mar	Crossover	Hopper	1000	70605	6789	2716
2	Jan-Mar	Moon Is.	Hopper	714	50412	4847	1939
2	Jan-Mar	Cow pt.Si	Clamshell	156	551	53	21
2	Jan-Mar	Aberdeen	Clamshell	670	2365	227	91
			Season Total:		123933	11917	4767
			% of G.H. Population		1.80	1.24	1.49
			% of Local Area Population		0.30	0.25	0.38
2	Apr-May	Entrance	Hopper	330	43535	14941	17774
			Season Total:		43535	14941	17774
			% of G.H. Population		0.02	0.47	1.27
			% of Local Area Population		0.02	0.20	0.63
2	Jun-Sep	Outer bar	Hopper	2800	229499	424026	157371
			Season Total:		229499	424026	157371
			% of G.H. Population		0.97	6.17	11.74
			% of Local Area Population		0.12	2.45	4.68
			Annual Total:		619747	514060	203187
			Project Totals		1002379	654520	298549

Table B3b: Immediate Dredge Mortality (Number of Crabs)
Without Confined Disposal, Linear Entr. Function, Mean Population

Year	Season	Reach	Equipment	Vol.	Age Class 0+	1+	>1+
1	Jan-Mar	South	Hopper	1698	39234	30777	19378
			Season Total:		39234	30777	19378
		% of G.H. Population			0.57	3.21	6.06
		% of Local Area Population			0.10	0.65	1.53
1	Apr-May	South	Hopper	1132	7467	30751	52436
1	Apr-May	Hoquiam	Clamshell	771	3182	173	68
			Season Total:		10649	30924	52504
		% of G.H. Population			0.01	0.96	3.75
		% of Local Area Population			0.00	0.41	1.88
1	Jun-Sep	Crossover	Hopper	1000	10048	30143	9342
1	Jun-Sep	Hoquiam	Clamshell	579	291	145	31
			Season Total:		10339	30288	9373
		% of G.H. Population			0.04	44	0.70
		% of Local Area Population			0.01	0.17	0.28
			Annual Total:		60222	91990	81255
2	Oct-Dec	Crossover	Hopper	250	4549	5547	2043
2	Oct-Dec	Moon Is.	Hopper	1786	32495	39625	14599
2	Oct-Dec	Cow pt.Si	Clamshell	778	354	100	37
2	Oct-Dec	Cow pt.Gr	Pipeline	374	34023	9648	3555
			Season Total:		71421	54920	20234
		% of G.H. Population			0.59	1.54	1.73
		% of Local Area Population			0.08	0.58	0.82
2	Jan-Mar	Crossover	Hopper	1000	28242	5838	2335
2	Jan-Mar	Moon Is.	Hopper	714	20165	4169	1667
2	Jan-Mar	Cow pt.Si	Clamshell	156	55	5	2
2	Jan-Mar	Aberdeen	Clamshell	670	237	23	9
			Season Total:		48698	10035	4014
		% of G.H. Population			0.71	1.05	1.25
		% of Local Area Population			0.12	0.21	0.32
2	Apr-May	Entrance	Hopper	330	2177	8965	15286
			Season Total:		2177	8965	15286
		% of G.H. Population			0.00	0.28	1.09
		% of Local Area Population			0.00	0.12	0.55
2	Jun-Sep	Outer bar	Hopper	2800	22950	254416	135339
			Season Total:		22950	254416	135339
		% of G.H. Population			0.10	3.70	10.10
		% of Local Area Population			0.01	1.47	4.03
			Annual Total:		145246	328336	174873
			Project Totals		205468	420325	256128

Table B3c: Relative Loss at Age 2+ (Number of Crabs)
Without Confined Disposal, Linear Entr. Function, Mean Population

Year	Season	Reach	Equipment	Vol.	Age Class 0+	1+	>1+
1	Jan-Mar	South	Hopper	1698	1059	6833	19378
			Season Total:		1059	6833	19378
			% of G.H. Population		0.57	3.21	6.06
			% of Local Area Population		0.10	0.65	1.53
1	Apr-May	South	Hopper	1132	22	1538	16622
1	Apr-May	Hoquiam	Clamshell	771	10	9	22
			Season Total:		32	1546	16644
			% of G.H. Population		0.01	0.96	3.75
			% of Local Area Population		0.00	0.41	1.88
1	Jun-Sep	Crossover	Hopper	1000	50	2472	4353
1	Jun-Sep	hoquiam	Clamshell	579	1	12	15
			Season Total:		52	2484	4368
			% of G.H. Population		0.04	0.44	0.70
			% of Local Area Population		0.01	0.17	0.28
			Annual Total:		1143	10862	40390
2	Oct-Dec	Crossover	Hopper	250	59	793	1461
2	Oct-Dec	Moon Is.	Hopper	1786	422	5666	10438
2	Oct-Dec	Cow pt.Si	Clamshell	778	5	14	26
2	Oct-Dec	Cow pt.Gr	Pipeline	374	442	1380	2542
			Season Total:		928	7854	14467
			% of G.H. Population		0.59	1.54	1.73
			% of Local Area Population		0.08	0.58	0.82
2	Jan-Mar	Crossover	Hopper	1000	763	1296	2335
2	Jan-Mar	Moon Is.	Hopper	714	544	925	1667
2	Jan-Mar	Cow pt.Si	Clamshell	156	1	1	2
2	Jan-Mar	Aberdeen	Clamshell	670	6	5	9
			Season Total:		1315	2228	4014
			% of G.H. Population		0.71	1.05	1.25
			% of Local Area Population		0.12	0.21	0.32
2	Apr-May	Entrance	Hopper	330	7	448	4846
			Season Total:		7	448	4846
			% of G.H. Population		0.00	0.28	1.09
			% of Local Area Population		0.00	0.12	0.55
2	Jun-Sep	Outer bar	Hopper	2800	115	20862	63068
			Season Total:		115	20862	63068
			% of G.H. Population		0.10	3.70	10.10
			% of Local Area Population		0.01	1.47	4.03
			Annual Total:		2365	31392	86395
			Project Totals		3508	42254	126785

Table B4a: Entrainment (Number of Crabs)
Without Confined Disposal, Curved Entr. Function, Best Population

Year	Season	Reach	Equipment	Vol.	Age Class 0+	1+	>1+
1	Jan-Mar	South	Hopper	1698	129993	8965	12167
			Season Total:		129993	8965	12167
			% of G.H. Population		1.21	1.25	3.48
			% of Local Area Population		0.34	0.86	1.67
1	Apr-May	South	Hopper	1132	577487	1234	39486
1	Apr-May	Hoquiam	Clamshell	771	3615877	10451	26873
			Season Total:		4193364	11684	66359
			% of G.H. Population		0.66	4.67	6.70
			% of Local Area Population		0.62	0.39	5.58
1	Jun-Sep	Crossover	Hopper	1000	285412	15094	13722
1	Jun-Sep	Hoquiam	Clamshell	579	8263	437	397
			Season Total:		293675	15531	14119
			% of G.H. Population		0.99	0.30	0.96
			% of Local Area Population		0.17	0.26	0.62
			Annual Total:		4617032	36180	92645
2	Oct-Dec	Crossover	Hopper	250	55084	1749	2623
2	Oct-Dec	Moon Is.	Hopper	1786	393517	12493	18739
2	Oct-Dec	Cow pt.Si	Clamshell	778	8571	272	408
2	Oct-Dec	Cow pt.Gr	Pipeline	374	82405	2616	3924
			Season Total:		539576	17129	25694
			% of G.H. Population		3.13	0.64	1.98
			% of Local Area Population		0.72	0.54	1.41
2	Jan-Mar	Crossover	Hopper	1000	110327	1511	1511
2	Jan-Mar	Moon Is.	Hopper	714	78774	1079	1079
2	Jan-Mar	Cow pt.Si	Clamshell	156	861	12	12
2	Jan-Mar	Aberdeen	Clamshell	670	3696	51	51
			Season Total:		193657	2653	2653
			% of G.H. Population		1.80	0.37	0.76
			% of Local Area Population		0.51	0.26	0.36
2	Apr-May	Entrance	Hopper	330	168349	360	11511
			Season Total:		168349	360	11511
			% of G.H. Population		0.03	0.14	1.16
			% of Local Area Population		0.03	0.01	0.97
2	Jun-Sep	Outer bar	Hopper	2800	811324	279767	226611
			Season Total:		811324	279767	226611
			% of G.H. Population		2.73	5.44	15.42
			% of Local Area Population		0.48	4.63	9.98
			Annual Total:		1712906	299909	266469
			Project Totals		6329938	336089	359114

Table B4b: Immediate Dredge Mortality (Number of Crabs)
Without Confined Disposal, Curved EF, Best Population

Year	Season	Reach	Equipment	Vol.	Age Class 0+	1+	>1+
1	Jan-Mar	South	Hopper	1698	51997	7710	10463
			Season Total:		51997	7710	10463
			% of G.H. Population		0.48	1.07	2.99
			% of Local Area Population		0.14	0.74	1.43
1	Apr-May	South	Hopper	1132	28874	740	33958
1	Apr-May	Hoquiam	Clamshell	771	361588	1045	2687
			Season Total:		390462	1785	36645
			% of G.H. Population		0.06	0.71	3.70
			% of Local Area Population		0.06	0.06	3.08
1	Jun-Sep	Crossover	Hopper	1000	28541	9056	11801
1	Jun-Sep	Hoquiam	Clamshell	579	826	44	40
			Season Total:		29367	9100	11840
			% of G.H. Population		0.10	0.18	0.81
			% of Local Area Population		0.02	0.15	0.52
			Annual Total:		471827	18595	58949
2	Oct-Dec	Crossover	Hopper	250	11017	1504	2256
2	Oct-Dec	Moon Is.	Hopper	1786	78703	10744	16115
2	Oct-Dec	Cow pt.Si	Clamshell	778	857	27	41
2	Oct-Dec	Cow pt.Gr	Pipeline	374	82405	2616	3924
			Season Total:		172982	14891	22336
			% of G.H. Population		1.00	0.56	1.72
			% of Local Area Population		0.23	0.47	1.23
2	Jan-Mar	Crossover	Hopper	1000	44131	1300	1300
2	Jan-Mar	Moon Is.	Hopper	714	31509	928	928
2	Jan-Mar	Cow pt.Si	Clamshell	156	86	1	1
2	Jan-Mar	Aberdeen	Clamshell	670	370	5	5
			Season Total:		76096	2234	2234
			% of G.H. Population		0.71	0.31	0.64
			% of Local Area Population		0.20	0.21	0.31
2	Apr-May	Entrance	Hopper	330	8417	216	9899
			Season Total:		8417	216	9899
			% of G.H. Population		0.00	0.09	1.00
			% of Local Area Population		0.00	0.01	0.83
2	Jun-Sep	Outer bar	Hopper	2800	81132	167860	194886
			Season Total:		81132	167860	194886
			% of G.H. Population		0.27	3.27	13.26
			% of Local Area Population		0.05	2.78	8.59
			Annual Total:		338628	185201	229355
			Project Totals		810454	203796	288305

Table B4c: Relative Loss at Age 2+ (Number of Crabs)
Without Confined Disposal, Curved EF, Best Population

Year	Season	Reach	Equipment	Vol.	Age Class 0+	1+	>1+
1	Jan-Mar	South	Hopper	1698	1404	1712	10463
			Season Total:		1404	1712	10463
			% of G.H. Population		0.48	1.07	2.99
			% of Local Area Population		0.14	0.74	1.43
1	Apr-May	South	Hopper	1132	87	37	10765
1	Apr-May	Hoquiam	Clamshell	771	1085	52	852
			Season Total:		1171	89	11617
			% of G.H. Population		0.06	0.71	3.70
			% of Local Area Population		0.06	0.06	3.08
1	Jun-Sep	Crossover	Hopper	1000	143	743	5499
1	Jun-Sep	Hoquiam	Clamshell	579	4	4	19
			Season Total:		147	746	5518
			% of G.H. Population		0.10	0.18	0.81
			% of Local Area Population		0.02	0.15	0.52
			Annual Total:		2722	2547	27598
2	Oct-Dec	Crossover	Hopper	250	143	215	1613
2	Oct-Dec	Moon Is.	Hopper	1786	1023	1536	11523
2	Oct-Dec	Cow pt.Si	Clamshell	778	11	4	29
2	Oct-Dec	Cow pt.Gr	Pipeline	374	1071	374	2806
			Season Total:		2249	2129	15970
			% f G.H. Population		1.00	0.56	1.72
			% of Local Area Population		0.23	0.47	1.23
2	Jan-Mar	Crossover	Hopper	1000	1192	289	1300
2	Jan-Mar	Moon Is.	Hopper	714	851	206	928
2	Jan-Mar	Cow pt.Si	Clamshell	156	2	0	1
2	Jan-Mar	Aberdeen	Clamshell	670	10	1	5
			Season Total:		2055	496	2234
			% of G.H. Population		0.71	0.31	0.64
			% of Local Area Population		0.20	0.21	0.31
2	Apr-May	Entrance	Hopper	330	25	11	3138
			Season Total:		25	11	3138
			% of G.H. Population		0.00	0.09	1.00
			% of Local Area Population		0.00	0.01	0.83
2	Jun-Sep	Outer bar	Hopper	2800	406	13765	90817
			Season Total:		406	13765	90817
			% of G.H. Population		0.27	3.27	13.?6
			% of Local Area Population		0.05	2.78	8.59
			Annual Total:		4734	16401	112159
			Project Totals		7456	18948	139757

Table B5a: Entrainment (Number of Crabs)
Without Confined Disposal, Curved Entr. Function, Worst Population

Year	Season	Reach	Equipment	Vol.	Age Class 0+	1+	>1+
1	Jan-Mar	South	Hopper	1698	4356	2772	3036
			Season Total:		4356	2772	3036
			% of G.H. Population		0.11	0.68	0.49
			% of Local Area Population		0.10	0.35	0.22
1	Apr-May	South	Hopper	1132	240493	190186	181597
1	Apr-May	Hoquiam	Clamshell	771	73	1038	234
			Season Total:		240566	191224	181831
			% of G.H. Population		0.15	3.82	5.88
			% of Local Area Population		0.14	2.43	4.76
1	Jun-Sep	Crossover	Hopper	1000	49068	60148	13454
1	Jun-Sep	Hoquiam	Clamshell	579	1421	1741	389
			Season Total:		50489	61889	13844
			% of G.H. Population		0.23	0.52	0.66
			% of Local Area Population		0.21	0.48	0.37
			Annual Total:		295411	255886	198711
2	Oct-Dec	Crossover	Hopper	250	80446	41972	26982
2	Oct-Dec	Moon Is.	Hopper	1786	574705	299846	192758
2	Oct-Dec	Cow pt.Si	Clamshell	778	12517	6531	4198
2	Oct-Dec	Cow pt.Gr	Pipeline	374	120347	62790	40365
			Season Total:		788015	411138	264303
			% of G.H. Population		6.22	8.64	11.44
			% of Local Area Population		5.79	7.64	7.75
2	Jan-Mar	Crossover	Hopper	1000	2985	649	1947
2	Jan-Mar	Moon Is.	Hopper	714	2131	463	1390
2	Jan-Mar	Cow pt.Si	Clamshell	156	23	5	15
2	Jan-Mar	Aberdeen	Clamshell	670	100	22	65
			Season Total:		5240	1139	3417
			% of G.H. Population		0.13	0.28	0.55
			% of Local Area Population		0.11	0.14	0.24
2	Apr-May	Entrance	Hopper	330	70108	55443	52939
			Season Total:		70108	55443	52939
			% of G.H. Population		0.04	1.11	1.71
			% of Local Area Population		0.04	0.70	1.39
2	Jun-Sep	Outer bar	Hopper	2800	426332	1828963	451912
			Season Total:		426332	1828963	451912
			% of G.H. Population		1.94	15.45	21.62
			% of Local Area Population		1.76	14.16	11.96
			Annual Total:		1289695	2296684	772571
			Project Totals		1585106	2552569	971282

Table B5b: Immediate Dredge Mortality (Number of Crabs)
Without Confined Disposal, Curved Entr. Function, Worst Population

Year	Season	Reach	Equipment	Vol.	Age Class 0+	1+	>1+
1	Jan-Mar	South	Hopper	1698	1742	2384	2611
			Season Total:		1742	2384	2611
			% of G.H. Population		0.04	0.58	0.42
			% of Local Area Population		0.04	0.30	0.19
1	Apr-May	South	Hopper	1132	12025	114112	156173
1	Apr-May	Hoquiam	Clamshell	771	7	104	23
			Season Total:		12032	114215	156197
			% of G.H. Population		0.01	2.28	5.05
			% of Local Area Population		0.01	1.45	4.09
1	Jun-Sep	Crossover	Hopper	1000	4907	36089	11571
1	Jun-Sep	Hoquiam	Clamshell	579	142	174	39
			Season Total:		5049	36263	11610
			% of G.H. Population		0.02	0.31	0.56
			% of Local Area Population		0.02	0.28	0.31
			Annual Total:		18823	152862	170417
2	Oct-Dec	Crossover	Hopper	250	16089	36096	23204
2	Oct-Dec	Moon Is.	Hopper	1786	114941	257868	165772
2	Oct-Dec	Cow pt.Si	Clamshell	778	1252	653	420
2	Oct-Dec	Cow pt.Gr	Pipeline	374	120347	62790	40365
			Season Total:		252629	357406	229761
			% of G.H. Population		1.99	7.51	9.95
			% of Local Area Population		1.86	6.64	6.74
2	Jan-Mar	Crossover	Hopper	1000	1194	558	1674
2	Jan-Mar	Moon Is.	Hopper	714	853	398	1195
2	Jan-Mar	Cow pt.Si	Clamshell	156	2	1	2
2	Jan-Mar	Aberdeen	Clamshell	670	10	2	7
			Season Total:		2059	959	2878
			% of G.H. Population		0.05	0.23	0.46
			% of Local Area Population		0.04	0.12	0.20
2	Apr-May	Entrance	Hopper	330	3505	33266	45528
			Season Total:		3505	33266	45528
			% of G.H. Population		0.00	0.66	1.47
			% of Local Area Population		0.00	0.42	1.19
2	Jun-Sep	Outer bar	Hopper	2800	42633	1097378	388644
			Season Total:		42633	1097378	388644
			% of G.H. Population		0.19	9.27	18.60
			% of Local Area Population		0.18	8.49	10.28
			Annual Total:		[illegible]	1489009	666810
			Project Totals		[illegible]	1641872	837228

Table B5c: Relative Loss at Age 2+ (Number of Crabs)
Without Confined Disposal, Curved Entr. Function, Worst Population

Year	Season	Reach	Equipment	Vol.	Age Class 0+	1+	>1+
1	Jan-Mar	South	Hopper	1698	47	529	2611
			Season Total:		47	529	2611
			% of G.H. Population		0.04	0.58	0.42
			% of Local Area Population		0.04	0.30	0.19
1	Apr-May	South	Hopper	1132	36	5706	49507
1	Apr-May	Hoquiam	Clamshell	771	0	5	7
			Season Total:		36	5711	49514
			% of G.H. Population		0.01	2.28	5.05
			% of Local Area Population		0.01	1.45	4.09
1	Jun-Sep	Crossover	Hopper	1000	25	2959	5392
1	Jun-Sep	Hoquiam	Clamshell	579	1	14	18
			Season Total:		25	2974	5410
			% of G.H. Population		0.02	0.31	0.56
			% of Local Area Population		0.02	0.28	0.31
			Annual Total:		108	9214	57535
2	Oct-Dec	Crossover	Hopper	250	209	5162	16591
2	Oct-Dec	Moon Is.	Hopper	1786	1494	36875	118527
2	Oct-Dec	Cow pt.Si	Clamshell	778	16	93	300
2	Oct-Dec	Cow pt.Gr	Pipeline	374	1565	8979	28861
			Season Total:		3284	51109	164279
			% of G.H. Population		1.99	7.51	9.95
			% of Local Area Population		1.86	6.64	6.74
2	Jan-Mar	Crossover	Hopper	1000	32	124	1674
2	Jan-Mar	Moon Is.	Hopper	714	23	88	1195
2	Jan-Mar	Cow pt.Si	Clamshell	156	0	0	2
2	Jan-Mar	Aberdeen	Clamshell	670	0	0	7
			Season Total:		56	213	2878
			% of G.H. Population		0.05	0.23	0.46
			% of Local Area Population		0.04	0.12	0.20
2	Apr-May	Entrance	Hopper	330	11	1663	14432
			Season Total:		11	1663	14432
			% of G.H. Population		0.00	0.66	1.47
			% of Local Area Population		0.00	0.42	1.19
2	Jun-Sep	Outer bar	Hopper	2800	213	89985	181108
			Season Total:		213	89985	181108
			% of G.H. Population		0.19	9.27	18.60
			% of Local Area Population		0.18	8.49	10.28
			Annual Total:		3563	142970	362697
			Project Totals		3672	152184	420233

Table 86a: Entrainment (Number of Crabs)
Without Confined Disposal, Curved Entr. Function, Mean Population

Year	Season	Reach	Equipment	Vol.	Age Class 0+	1+	>1+
1	Jan-Mar	South	Hopper	1698	17832	6506	4097
			Season Total:		17832	6506	4097
			% of G.H. Population		0.26	0.68	1.28
			% of Local Area Population		0.04	0.14	0.32
1	Apr-May	South	Hopper	1132	99296	34078	40541
1	Apr-May	Hoquiam	Clamshell	771	141232	7666	3020
			Season Total:		240529	41744	43561
			% of G.H. Population		0.11	1.30	3.11
			% of Local Area Population		0.11	0.55	1.56
1	Jun-Sep	Crossover	Hopper	1000	40345	20173	4362
1	Jun-Sep	Hoquiam	Clamshell	579	1168	584	126
			Season Total:		41513	20757	4488
			% of G.H. Population		0.18	0.30	0.33
			% of Local Area Population		0.02	0.12	0.13
			Annual Total:		299874	69007	52145
2	Oct-Dec	Crossover	Hopper	250	6451	1829	674
2	Oct-Dec	Moon Is.	Hopper	1786	46085	13069	4815
2	Oct-Dec	Cow pt.Si	Clamshell	778	1004	285	105
2	Oct-Dec	Cow pt.Gr	Pipeline	374	9650	2737	1008
			Season Total:		63190	17920	6602
			% of G.H. Population		0.52	0.50	0.56
			% of Local Area Population		0.07	0.19	0.27
2	Jan-Mar	Crossover	Hopper	1000	10543	1014	405
2	Jan-Mar	Moon Is.	Hopper	714	7527	724	290
2	Jan-Mar	Cow pt.Si	Clamshell	156	82	8	3
2	Jan-Mar	Aberdeen	Clamshell	670	353	34	14
			Season Total:		18505	1779	712
			% of G.H. Population		0.27	0.19	0.22
			% of Local Area Population		0.04	0.04	0.06
2	Apr-May	Entrance	Hopper	330	28947	9934	11819
			Season Total:		28947	9934	11819
			% of G.H. Population		0.01	0.31	0.84
			% of Local Area Population		0.01	0.13	0.42
2	Jun-Sep	Outer bar	Hopper	2800	209818	387664	143875
			Season Total:		209818	387664	143875
			% of G.H. Population		0.88	5.64	10.74
			% of Local Area Population		0.11	2.24	4.28
			Annual Total:		320460	417298	163008
			Project Totals		620334	486304	215153

Table B6b: Immediate Dredge Mortality (Number of Crabs)
Without Confined Disposal, Curved Entr. Function, Mean Population

Year	Season	Reach	Equipment	Vol.	Age Class 0+	1+	>1+
1	Jan-Mar	South	Hopper	1698	7133	5595	3523
			Season Total:		7133	5595	3523
			% of G.H. Population		0.10	0.58	1.10
			% of Local Area Population		0.02	0.12	0.28
1	Apr-May	South	Hopper	1132	4965	20447	34865
1	Apr-May	Hoquiam	Clamshell	771	14123	767	302
			Season Total:		19088	21213	35167
			% of G.H. Population		0.01	0.66	2.51
			% of Local Area Population		0.01	0.28	1.26
1	Jun-Sep	Crossover	Hopper	1000	4035	12104	3751
1	Jun-Sep	Hoquiam	Clamshell	579	117	58	13
			Season Total:		4151	12162	3764
			% of G.H. Population		0.02	0.18	0.28
			% of Local Area Population		0.00	0.07	0.11
			Annual Total:		30372	38971	42454
2	Oct-Dec	Crossover	Hopper	250	1290	1573	580
2	Oct-Dec	Moon Is.	Hopper	1786	9217	11239	4141
2	Oct-Dec	Cow pt.Si	Clamshell	778	100	28	10
2	Oct-Dec	Cow pt.Gr	Pipeline	374	9650	2737	1008
			Season Total:		20258	15578	5739
			% of G.H. Population		0.17	0.44	0.49
			% of Local Area Population		0.02	0.16	0.23
2	Jan-Mar	Crossover	Hopper	1000	4217	872	349
2	Jan-Mar	Moon Is.	Hopper	714	3011	622	249
2	Jan-Mar	Cow pt.Si	Clamshell	156	8	1	0
2	Jan-Mar	Aberdeen	Clamshell	670	35	3	1
			Season Total:		7272	1498	599
			% of G.H. Population		0.11	0.16	0.19
			% of Local Area Population		0.02	0.03	0.05
2	Apr-May	Entrance	Hopper	330	1447	5961	10164
			Season Total:		1447	5961	10164
			% of G.H. Population		0.00	0.19	0.73
			% of Local Area Population		0.00	0.08	0.36
2	Jun-Sep	Outer bar	Hopper	2800	20982	232599	123733
			Season Total:		20982	232599	123733
			% of G.H. Population		0.09	3.39	9.23
			% of Local Area Population		0.01	1.34	3.68
			Annual Total:		49959	255635	140235
			Project Totals		80331	294606	182689

Table B6c: Relative Loss at Age 2+ (Number of Crabs)
Without Confined Disposal, Curved Entr. Function, Mean Population

Year	Season	Reach	Equipment	Vol.	Age Class 0+	1+	>1+
1	Jan-Mar	South	Hopper	1698	193	1242	3523
			Season Total:		193	1242	3523
			% of G.H. Population		0.10	0.58	1.10
			% of Local Area Population		0.02	0.12	0.28
1	Apr-May	South	Hopper	1132	15	1022	11052
1	Apr-May	Hoquiam	Clamshell	771	42	38	96
			Season Total:		57	1061	11148
			% of G.H. Population		0.01	0.66	2.51
			% of Local Area Population		0.01	0.28	1.26
1	Jun-Sep	Crossover	Hopper	1000	20	992	1748
1	Jun-Sep	Hoquiam	Clamshell	579	1	5	6
			Season Total:		21	997	1754
			% of G.H. Population		0.02	0.18	0.28
			% of Local Area Population		0.00	0.07	0.11
			Annual Total:		271	3300	16425
2	Oct-Dec	Crossover	Hopper	250	17	225	414
2	Oct-Dec	Moon Is.	Hopper	1786	120	1607	2961
2	Oct-Dec	Cow pt.Si	Clamshell	778	1	4	7
2	Oct-Dec	Cow pt.Gr	Pipeline	374	125	391	721
			Season Total:		263	2228	4103
			% of G.H. Population		0.17	0.44	0.49
			% of Local Area Population		0.02	0.16	0.23
2	Jan-Mar	Crossover	Hopper	1000	114	194	349
2	Jan-Mar	Moon Is.	Hopper	714	81	138	249
2	Jan-Mar	Cow pt.Si	Clamshell	156	0	0	0
2	Jan-Mar	Aberdeen	Clamshell	670	1	1	1
			Season Total:		196	333	599
			% of G.H. Population		0.11	0.16	0.19
			% of Local Area Population		0.02	0.03	0.05
2	Apr-May	Entrance	Hopper	330	4	298	3222
			Season Total:		4	298	3222
			% of G.H. Population		0.00	0.19	0.73
			% of Local Area Population		0.00	0.08	0.36
2	Jun-Sep	Outer bar	Hopper	2800	105	19073	57659
			Season Total:		105	19073	57659
			% of G.H. Population		0.09	3.39	9.23
			% of Local Area Population		0.01	1.34	3.68
			Annual Total:		569	21931	65584
			Project Totals		840	25231	82009

Table B7a: Entrainment (Number of Crabs)
Confined Disposal, Linear Entr. Function, Best Population

Year	Season	Reach	Equipment	Vol.	Age Class 0+	1+	>1+
1	Jan-Mar	South	Hopper	1698	269071	18557	25184
				Season Total:	269071	18557	25184
				% of G.H. Population	2.50	2.58	7.20
				% of Local Area Population	0.70	1.78	3.45
1	Apr-May	South	Hopper	1132	413547	884	28277
				Season Total:	413547	884	28277
				% of G.H. Population	0.06	0.35	2.86
				% of Local Area Population	0.06	0.03	2.38
1	Jun-Sep	Crossover	Hopper	1000	282420	14936	13578
1	Jun-Sep	Hoquiam	Pipeline	434	122570	6482	5893
				Season Total:	404991	21418	19471
				% of G.H. Population	1.36	0.42	1.32
				% of Local Area Population	0.24	0.35	0.86
				Annual Total:	1087609	40858	72931
2	Oct-Dec	Crossover	Hopper	250	64156	2037	3055
2	Oct-Dec	Moon Is.	Hopper	1786	458327	14550	21825
2	Oct-Dec	Hoquiam	Pipeline	916	235066	7462	11194
2	Oct-Dec	Cow pt.Si	Pipeline	934	239685	7609	11414
2	Oct-Dec	Cow pt.Gr	Pipeline	374	95977	3047	4570
				Season Total:	1093211	34705	52058
				% of G.H. Population	6.34	1.30	4.00
				% of Local Area Population	1.45	1.09	2.86
2	Jan-Mar	Crossover	Hopper	1000	198237	2716	2716
2	Jan-Mar	Moon Is.	Hopper	714	141541	1939	1939
2	Jan-Mar	Aberdeen	Pipeline	670	132819	1819	1819
				Season Total:	472598	6474	6474
				% of G.H. Population	4.39	0.90	1.85
				% of Local Area Population	1.23	0.62	0.89
2	Apr-May	Entrance	Hopper	330	120557	258	8243
				Season Total:	120557	258	8243
				% of G.H. Population	0.02	0.10	0.83
				% of Local Area Population	0.02	0.01	0.69
2	Jun-Sep	Outer bar	Hopper	2800	633854	218570	177042
				Season Total:	633854	218570	177042
				% of G.H. Population	2.13	4.25	12.04
				% of Local Area Population	0.38	3.62	7.80
				Annual Total:	2320219	260007	243817
				Project Totals:	3407829	300865	316748

Table B7b: Immediate Dredge Mortality (Number of Crabs)
Confined Disposal, Linear Entr. Function, Best Population

Year	Season	Reach	Equipment	Vol.	Age Class 0+	1+	>1+
1	Jan-Mar	South	Hopper	1698	107628	15959	21658
				Season Total:	107628	15959	21658
				% of G.H. Population	1.00	2.22	6.19
				% of Local Area Population	0.28	1.53	2.97
1	Apr-May	South	Hopper	1132	20677	530	24318
				Season Total:	20677	530	24318
				% of G.H. Population	0.00	0.21	2.46
				% of Local Area Population	0.00	0.02	2.04
1	Jun-Sep	Crossover	Hopper	1000	28242	8961	11677
1	Jun-Sep	Hoquiam	Pipeline	434	122570	6482	5893
				Season Total:	150812	15443	17570
				% of G.H. Population	0.51	0.30	1.20
				% of Local Area Population	0.09	0.26	0.77
				Annual Total:	279118	31932	63546
2	Oct-Dec	Crossover	Hopper	250	12831	1752	2627
2	Oct-Dec	Moon Is.	Hopper	1786	91665	12513	18770
2	Oct-Dec	Hoquiam	Pipeline	916	235066	7462	11194
2	Oct-Dec	Cow pt.Si	Pipeline	934	239685	7609	11414
2	Oct-Dec	Cow pt.Gr	Pipeline	374	95977	3047	4570
				Season Total:	675224	32383	48574
				% of G.H. Population	3.92	1.21	3.74
				% of Local Area Population	0.90	1.02	2.67
2	Jan-Mar	Crossover	Hopper	1000	79295	2335	2335
2	Jan-Mar	Moon Is.	Hopper	714	56617	1667	1667
2	Jan-Mar	Aberdeen	Pipeline	670	132819	1819	1819
				Season Total:	268730	5822	5822
				% of G.H. Population	2.50	0.81	1.66
				% of Local Area Population	0.70	0.56	0.80
2	Apr-May	Entrance	Hopper	330	6028	155	7089
				Season Total:	6028	155	7089
				% of G.H. Population	0.00	0.06	0.72
				% of Local Area Population	0.00	0.01	0.60
2	Jun-Sep	Outer bar	Hopper	2800	63385	131142	152256
				Season Total:	63385	131142	152256
				% of G.H. Population	0.21	2.55	10.36
				% of Local Area Population	0.04	2.17	6.71
				Annual Total:	1013368	169502	213742
				Project Totals	1292486	201434	277288

Table B7c: Relative Loss at Age 2+ (Number of Crabs)
Confined Disposal, Linear Entr. Function, Best Population

Year	Season	Reach	Equipment	Vol.	Age Class 0+	1+	>1+
1	Jan-Mar	South	Hopper	1698	2906	3543	21658
				Season Total:	2906	3543	21658
				% of G.H. Population	1.00	2.22	6.19
				% of Local Area Population	0.28	1.53	2.97
1	Apr-May	South	Hopper	1132	62	27	7709
				Season Total:	62	27	7709
				% of G.H. Population	0.00	0.21	2.46
				% of Local Area Population	0.00	0.02	2.04
1	Jun-Sep	Crossover	Hopper	1000	141	735	5441
1	Jun-Sep	Hoquiam	Pipeline	434	613	532	2746
				Season Total:	754	1266	8188
				% of G.H. Population	0.51	0.30	1.20
				% of Local Area Population	0.09	0.26	0.77
				Annual Total:	3722	4836	37555
2	Oct-Dec	Crossover	Hopper	250	167	250	1879
2	Oct-Dec	Moon Is.	Hopper	1786	1192	1789	13420
2	Oct-Dec	Hoquiam	Pipeline	916	3056	1067	8003
2	Oct-Dec	Cow pt.Si	Pipeline	934	3116	1088	8161
2	Oct-Dec	Cow pt.Gr	Pipeline	374	1248	436	3268
				Season Total:	8778	4631	34731
				% of G.H. Population	3.92	1.21	3.74
				% of Local Area Population	0.90	1.02	2.67
2	Jan-Mar	Crossover	Hopper	1000	2141	518	2335
2	Jan-Mar	Moon Is.	Hopper	714	1529	370	1667
2	Jan-Mar	Aberdeen	Pipeline	670	3586	404	1819
				Season Total:	7256	1293	5822
				% of G.H. Population	2.50	0.81	1.66
				% of Local Area Population	0.70	0.56	0.80
2	Apr-May	Entrance	Hopper	330	18	8	2247
				Season Total:	18	8	2247
				% of G.H. Population	0.00	0.06	0.72
				% of Local Area Population	0.00	0.01	0.60
2	Jun-Sep	Outer bar	Hopper	2800	317	10754	70951
				Season Total:	317	10754	70951
				% of G.H. Population	0.21	2.55	10.36
				% of Local Area Population	0.04	2.17	6.71
				Annual Total:	16369	16685	113752
				Project Totals	20091	21520	151306

Table B8a: Entrainment (Number of Crabs)
Confined Disposal, Linear Entr. Function, Worst Population

Year	Season	Reach	Equipment	Vol.	Age Class 0+	1+	>1+
1	Jan-Mar	South	Hopper	1698	43741	27835	30486
			Season Total:		43741	27835	30486
			% of G.H. Population		1.06	6.79	4.92
			% of Local Area Population		0.96	3.48	2.16
1	Apr-May	South	Hopper	1132	173195	136965	130780
			Season Total:		173195	136965	130780
			% of G.H. Population		0.11	2.73	4.23
			% of Local Area Population		0.10	1.74	3.42
1	Jun-Sep	Crossover	Hopper	1000	84183	103192	23082
1	Jun-Sep	Hoquiam	Pipeline	434	36535	44785	10018
			Season Total:		120718	147977	33100
			% of G.H. Population		0.55	1.25	1.58
			% of Local Area Population		0.50	1.15	0.88
			Annual Total:		337654	312778	194366
2	Oct-Dec	Crossover	Hopper	250	54651	28514	18330
2	Oct-Dec	Moon Is.	Hopper	1786	390427	203701	130951
2	Oct-Dec	Hoquiam	Pipeline	916	200241	104474	67162
2	Oct-Dec	Cow pt.Si	Pipeline	934	204176	106527	68481
2	Oct-Dec	Cow pt.Gr	Pipeline	374	81758	42656	27422
			Season Total:		931253	485871	312346
			% of G.H. Population		7.35	10.21	13.52
			% of Local Area Population		6.84	9.03	9.16
2	Jan-Mar	Crossover	Hopper	1000	31229	6789	20367
2	Jan-Mar	Moon Is.	Hopper	714	22298	4847	14542
2	Jan-Mar	Aberdeen	Pipeline	670	20924	4549	13646
			Season Total:		74450	16185	48555
			% of G.H. Population		1.80	3.95	7.83
			% of Local Area Population		1.63	2.02	3.44
2	Apr-May	Entrance	Hopper	330	50490	39928	38125
			Season Total:		50490	39928	38125
			% of G.H. Population		0.03	0.80	1.23
			% of Local Area Population		0.03	0.51	1.00
2	Jun-Sep	Outer bar	Hopper	2800	218570	937666	231684
			Season Total:		218570	937666	231684
			% of G.H. Population		0.99	7.92	11.09
			% of Local Area Population		0.90	7.26	6.13
			Annual Total:		1274764	1479651	630710
			Project Totals		1612418	1792428	825076

Table B8b: Immediate Dredge Mortality (Number of Crabs)
Confined Disposal, Linear Entr. Function, Worst Population

Year	Season	Reach	Equipment	Vol.	Age Class 0+	1+	>1+
1	Jan-Mar	South	Hopper	1698	17496	23938	26218
			Season Total:		17496	23938	26218
			% of G.H. Population		0.42	5.84	4.23
			% of Local Area Population		0.38	2.99	1.86
1	Apr-May	South	Hopper	1132	8660	82179	112471
			Season Total:		8660	82179	112471
			% of G.H. Population		0.01	1.64	3.64
			% of Local Area Population		0.00	1.04	2.94
1	Jun-Sep	Crossover	Hopper	1000	8418	61915	19851
1	Jun-Sep	Hoquiam	Pipeline	434	36535	44785	10018
			Season Total:		44954	106701	29869
			% of G.H. Population		0.20	0.90	1.43
			% of Local Area Population		0.19	0.83	0.79
			Annual Total:		71110	212818	168557
2	Oct-Dec	Crossover	Hopper	250	10930	24522	15764
2	Oct-Dec	Moon Is.	Hopper	1786	78085	175183	112618
2	Oct-Dec	Hoquiam	Pipeline	916	200241	104474	67162
2	Oct-Dec	Cow pt.Si	Pipeline	934	204176	106527	68481
2	Oct-Dec	Cow pt.Gr	Pipeline	374	81758	42656	27422
			Season Total:		575191	453361	291447
			% of G.H. Population		4.54	9.52	12.62
			% of Local Area Population		4.23	8.43	8.55
2	Jan-Mar	Crossover	Hopper	1000	12492	5838	17515
2	Jan-Mar	Moon Is.	Hopper	714	8919	4169	12506
2	Jan-Mar	Aberdeen	Pipeline	670	20924	4549	13646
			Season Total:		42334	14556	43667
			% of G.H. Population		1.02	3.55	7.04
			% of Local Area Population		0.92	1.82	3.10
2	Apr-May	Entrance	Hopper	330	2524	23957	32787
			Season Total:		2524	23957	32787
			% of G.H. Population		0.00	0.48	1.06
			% of Local Area Population		0.00	0.30	0.86
2	Jun-Sep	Outer bar	Hopper	2800	21857	562600	199249
			Season Total:		21857	562600	199249
			% of G.H. Population		0.10	4.75	9.53
			% of Local Area Population		0.09	4.35	5.27
			Annual Total:		641907	1054474	567150
			Project Totals		713017	1267292	735707

Table B8c: Relative Loss at Age 2+ (Number of Crabs)
Confined Disposal, Linear Entr. Function, Worst Population

Year	Season	Reach	Equipment	Vol.	Age Class 0+	1+	>1+
1	Jan-Mar	South	Hopper	1698	472	5314	26218
			Season Total:		472	5314	26218
			% of G.H. Population		0.42	5.84	4.23
			% of Local Area Population		0.38	2.99	1.86
1	Apr-May	South	Hopper	1132	26	4109	35653
			Season Total:		26	4109	35653
			% of G.H. Population		0.01	1.64	3.64
			% of Local Area Population		0.00	1.04	2.94
1	Jun-Sep	Crossover	Hopper	1000	42	5077	9251
1	Jun-Sep	Hoquiam	Pipeline	434	183	3672	4668
			Season Total:		225	8749	13919
			% of G.H. Population		0.20	0.90	1.43
			% of Local Area Population		0.19	0.83	0.79
			Annual Total:		723	18173	75790
2	Oct-Dec	Crossover	Hopper	250	142	3507	11271
2	Oct-Dec	Moon Is.	Hopper	1786	1015	25051	80522
2	Oct-Dec	Hoquiam	Pipeline	916	2603	14940	48021
2	Oct-Dec	Cow pt.Si	Pipeline	934	2654	15233	48964
2	Oct-Dec	Cow pt.Gr	Pipeline	374	1063	6100	19607
			Season Total:		7477	64831	208384
			% of G.H. Population		4.54	9.52	12.62
			% of Local Area Population		4.23	8.43	8.55
2	Jan-Mar	Crossover	Hopper	1000	337	1296	17515
2	Jan-Mar	Moon Is.	Hopper	714	241	925	12506
2	Jan-Mar	Aberdeen	Pipeline	670	565	1010	13646
			Season Total:		1143	3231	43667
			% of G.H. Population		1.02	3.55	4.04
			% of Local Area Population		0.92	1.82	3.10
2	Apr-May	Entrance	Hopper	330	8	1198	10394
			Season Total:		8	1198	10394
			% of G.H. Population		0.00	0.48	1.06
			% of Local Area Population		0.00	0.30	0.86
2	Jun-Sep	Outer bar	Hopper	2800	109	46133	92850
			Season Total:		109	46133	92850
			% of G.H. Population		0.10	4.75	9.53
			% of Local Area Population		0.09	4.35	5.27
			Annual Total:		8737	115393	355295
			Project Totals		9461	133566	431085

Table B9a: Entrainment (Number of Crabs)
Confined Disposal, Linear Entr.Function, Mean Pop

Year	Season	Reach	Equipment	Vol.	Age Class 0+	1+	>1+
1	Jan-Mar	South	Hopper	1698	98085	35788	22533
			Season Total:		98085	35788	22533
			% of G.H. Population		1.43	3.73	7.04
			% of Local Area Population		0.24	0.76	1.77
1	Apr-May	South	Hopper	1132	149337	51252	60972
			Season Total:		149337	51252	60972
			% of G.H. Population		0.07	1.60	4.36
			% of Local Area Population		0.07	0.67	2.18
1	Jun-Sep	Crossover	Hopper	1000	100476	50238	10862
1	Jun-Sep	Hoquiam	Pipeline	434	43607	21803	4714
			Season Total:		144083	72042	15577
			% of G.H. Population		0.61	1.05	1.16
			% of Local Area Population		0.07	0.42	0.46
			Annual Total:		391505	159081	99081
2	Oct-Dec	Crossover	Hopper	250	22743	6449	2376
2	Oct-Dec	Moon Is.	Hopper	1786	162476	46075	16975
2	Oct-Dec	Hoquiam	Pipeline	916	83330	23631	8706
2	Oct-Dec	Cow pt.Si	Pipeline	934	84968	24095	8877
2	Oct-Dec	Cow pt.Gr	Pipeline	374	34023	9648	3555
			Season Total:		387540	109899	40489
			% of G.H. Population		3.21	3.08	3.46
			% of Local Area Population		0.46	1.15	1.63
2	Jan-Mar	Crossover	Hopper	1000	70605	6789	2716
2	Jan-Mar	Moon Is.	Hopper	714	50412	4847	1939
2	Jan-Mar	Aberdeen	Pipeline	670	47305	4549	1819
			Season Total:		168322	16185	6474
			% of G.H. Population		2.45	1.69	2.02
			% of Local Area Population		0.41	0.34	0.51
2	Apr-May	Entrance	Hopper	330	43535	14941	17774
			Season Total:		43535	14941	17774
			% of G.H. Population		0.02	0.47	1.27
			% of Local Area Population		0.02	0.20	0.63
2	Jun-Sep	Outer bar	Hopper	2800	229499	424026	157371
			Season Total:		229499	424026	157371
			% of G.H. Population		0.97	6.17	11.74
			% of Local Area Population		0.12	2.45	4.68
			Annual Total:		828896	565051	222108
			Project Totals		1220401	724132	321190

Table B9b: Immediate Dredge Mortality (Number of Crabs)
Confined Disposal, Linear Entr.Function, Mean Pop

Year	Season	Reach	Equipment	Vol.	Age Class 0+	1+	>1+
1	Jan-Mar	South	Hopper	1698	39234	30777	19378
				Season Total:	39234	30777	19378
				% of G.H. Population	0.57	3.21	6.06
				% of Local Area Population	0.10	0.65	1.53
1	Apr-May	South	Hopper	1132	7467	30751	52436
				Season Total:	7467	30751	52436
				% of G.H. Population	0.00	0.96	3.75
				% of Local Area Population	0.00	0.40	1.87
1	Jun-Sep	Crossover	Hopper	1000	10048	30143	9342
1	Jun-Sep	Hoquiam	Pipeline	434	43607	21803	4714
				Season Total:	53654	51946	14056
				% of G.H. Population	0.23	0.76	1.05
				% of Local Area Population	0.03	0.30	0.42
				Annual Total:	100355	113475	85870
2	Oct-Dec	Crossover	Hopper	250	4549	5547	2043
2	Oct-Dec	Moon Is.	Hopper	1786	32495	39625	14599
2	Oct-Dec	Hoquiam	Pipeline	916	83330	23631	8706
2	Oct-Dec	Cow pt.Si	Pipeline	934	84968	24095	8877
2	Oct-Dec	Cow pt.Gr	Pipeline	374	34023	9648	3555
				Season Total:	239365	102546	37780
				% of G.H. Population	1.98	2.87	3.23
				% of Local Area Population	0.28	1.07	1.52
2	Jan-Mar	Crossover	Hopper	1000	28242	5838	2335
2	Jan-Mar	Moon Is.	Hopper	714	20165	4169	1667
2	Jan-Mar	Aberdeen	Pipeline	670	47305	4549	1819
				Season Total:	95712	14556	5822
				% of G.H. Population	1.39	1.52	1.82
				% of Local Area Population	0.23	0.31	0.46
2	Apr-May	Entrance	Hopper	330	2177	8965	15286
				Season Total:	2177	8965	15286
				% of G.H. Population	0.00	0.28	1.09
				% of Local Area Population	0.00	0.12	0.55
2	Jun-Sep	Outer bar	Hopper	2800	22950	254416	135339
				Season Total:	22950	254416	135339
				% of G.H. Population	0.10	3.70	10.10
				% of Local Area Population	0.01	1.47	4.03
				Annual Total:	360204	380482	194227
				Project Totals	460559	493957	280097

Table B9c: Relative Loss at Age 2+ (Number of Crabs)
Confined Disposal, Linear Entr. Function, Mean Pop

Year	Season	Reach	Equipment	Vol.	Age Class 0+	1+	>1+
1	Jan-Mar	South	Hopper	1698	1059	6833	19378
			Season Total:		1059	6833	19378
			% of G.H. Population		0.57	3.21	6.06
			% of Local Area Population		0.10	0.65	1.53
1	Apr-May	South	Hopper	1132	22	1538	16622
			Season Total:		22	1538	16622
			% of G.H. Population		0.00	0.96	3.75
			% of Local Area Population		0.00	0.40	1.87
1	Jun-Sep	Crossover	Hopper	1000	50	2472	4353
1	Jun-Sep	Hoquiam	Pipeline	434	218	1788	2197
			Season Total:		268	4260	6550
			% of G.H. Population		0.23	0.76	1.05
			% of Local Area Population		0.03	0.30	0.42
			Annual Total:		1350	12630	42551
2	Oct-Dec	Crossover	Hopper	250	59	793	1461
2	Oct-Dec	Moon Is.	Hopper	1786	422	5666	10438
2	Oct-Dec	Hoquiam	Pipeline	916	1083	3379	6225
2	Oct-Dec	Cow pt.Si	Pipeline	934	1105	3446	6347
2	Oct-Dec	Cow pt.Gr	Pipeline	374	442	1380	2542
			Season Total:		3112	14664	27013
			% of G.H. Population		1.98	2.87	3.23
			% of Local Area Population		0.28	1.07	1.52
2	Jan-Mar	Crossover	Hopper	1000	763	1296	2335
2	Jan-Mar	Moon Is.	Hopper	714	544	925	1667
2	Jan-Mar	Aberdeen	Pipeline	670	1277	1010	1819
			Season Total:		2584	3231	5822
			% of G.H. Population		1.39	1.52	1.82
			% of Local Area Population		0.23	0.31	0.46
2	Apr-May	Entrance	Hopper	330	7	448	4846
			Season Total:		7	448	4846
			% of G.H. Population		0.00	0.28	1.09
			% of Local Area Population		0.00	0.12	0.55
2	Jun-Sep	Outer bar	Hopper	2800	115	20862	63068
			Season Total:		115	20862	63068
			% of G.H. Population		0.10	3.70	10.10
			% of Local Area Population		0.01	1.47	4.03
			Annual Total:		5817	39206	100749
			Project Totals		7167	51836	143299

Table B10a: Entrainment (Number of Crabs)
Confined Disposal, curved Entr.Function, Best Population

Year	Season	Reach	Equipment	Vol.	Age Class 0+	1+	>1+
1	Jan-Mar	South	Hopper	1698	129993	8965	12167
			Season Total:		129993	8965	12167
		% of G.H. Population			1.21	1.25	3.48
		% of Local Area Population			0.34	0.86	1.67
1	Apr-May	South	Hopper	1132	577487	1234	39486
			Season Total:		577487	1234	39486
		% of G.H. Population			0.09	0.49	3.99
		% of Local Area Population			0.09	0.04	3.32
1	Jun-Sep	Crossover	Hopper	1000	285412	15094	13722
1	Jun-Sep	Hoquiam	Pipeline	434	123869	6551	5955
			Season Total:		409281	21645	19677
		% of G.H. Population			1.37	0.42	1.34
		% of Local Area Population			0.24	0.36	0.87
			Annual Total:		1116761	31844	71330
2	Oct-Dec	Crossover	Hopper	250	55084	1749	2623
2	Oct-Dec	Moon Is.	Hopper	1786	393517	12493	18739
2	Oct-Dec	Hoquiam	Pipeline	916	201826	6407	9611
2	Oct-Dec	Cow pt.Si	Pipeline	934	205792	6533	9800
2	Oct-Dec	Cow pt.Gr	Pipeline	374	82405	2616	3924
			Season Total:		938623	29798	44696
		% of G.H. Population			5.45	1.12	3.44
		% of Local Area Population			1.24	0.94	2.46
2	Jan-Mar	Crossover	Hopper	1000	110327	1511	1511
2	Jan-Mar	Moon Is.	Hopper	714	78774	1079	1079
2	Jan-Mar	Aberdeen	Pipeline	670	73919	1013	1013
			Season Total:		263020	3603	3603
		% of G.H. Population			2.44	0.50	1.03
		% of Local Area Population			0.69	0.35	0.49
2	Apr-May	Entrance	Hopper	330	168349	360	11511
			Season Total:		168349	360	11511
		% of G.H. Population			0.03	0.14	1.16
		% of Local Area Population			0.03	0.01	0.97
2	Jun-Sep	Outer bar	Hopper	2800	811324	279767	226611
			Season Total:		811324	279767	226611
		% of G.H. Population			2.73	5.44	15.42
		% of Local Area Population			0.48	4.63	9.98
			Annual Total:		2181316	313527	286422
			Project Totals		3298077	345371	357752

Tabel B10b: Immediate Dredge Mortality (Number of Crabs)
Confined Disposal, curved Entr. Function, Best Population

Year	Season	Reach	Equipment	Vol.	Age Class 0+	1+	>1+
1	Jan-Mar	South	Hopper	1698	51997	7710	10463
			Season Total:		51997	7710	10463
			% of G.H. Population		0.48	1.07	2.99
			% of Local Area Population		0.14	0.74	1.43
1	Apr-May	South	Hopper	1132	28874	740	33958
			Season Total:		28874	740	33958
			% of G.H. Population		0.00	0.30	3.43
			% of Local Area Population		0.00	0.02	2.85
1	Jun-Sep	Crossover	Hopper	1000	28541	9056	11801
1	Jun-Sep	Hoquiam	Pipeline	434	123869	6551	5955
			Season Total:		152410	15607	17756
			% of G.H. Population		0.51	0.30	1.21
			% of Local Area Population		0.09	0.26	0.78
			Annual Total:		233282	24057	62178
2	Oct-Dec	Crossover	Hopper	250	11017	1504	2256
2	Oct-Dec	Moon Is.	Hopper	1786	78703	10744	16115
2	Oct-Dec	Hoquiam	Pipeline	916	201826	6407	9611
2	Oct-Dec	Cow pt.Si	Pipeline	934	205792	6533	9800
2	Oct-Dec	Cow pt.Gr	Pipeline	374	82405	2616	3924
			Season Total:		579743	27804	41706
			% of G.H. Population		3.36	1.04	3.21
			% of Local Area Population		0.77	0.87	2.29
2	Jan-Mar	Crossover	Hopper	1000	44131	1300	1300
2	Jan-Mar	Moon Is.	Hopper	714	31509	928	928
2	Jan-Mar	Aberdeen	Pipeline	670	73919	1013	1013
			Season Total:		149560	3240	3240
			% of G.H. Population		1.39	0.45	0.93
			% of Local Area Population		0.39	0.31	0.44
2	Apr-May	Entrance	Hopper	330	8417	216	9899
			Season Total:		8417	216	9899
			% of G.H. Population		0.00	0.09	1.00
			% of Local Area Population		0.00	0.01	0.83
2	Jun-Sep	Outer bar	Hopper	2800	81132	167860	194886
			Season Total:		81132	167860	194886
			% of G.H. Population		0.27	3.27	13.26
			% of Local Area Population		0.05	2.78	8.59
			Annual Total:		818852	199120	249731
			Project Totals		1052134	223177	311909

Table B10c: Relative Loss at Age 2+ (Number of Crabs)
Confined Disposal, curved Entr. Function, Best Population

Year	Season	Reach	Equipment	Vol.	Age Class 0+	1+	>1+
1	Jan-Mar	South	Hopper	1698	1404	1712	10463
			Season Total:		1404	1712	10463
			% of G.H. Population		0.48	1.07	2.99
			% of Local Area Population		0.14	0.74	1.43
1	Apr-May	South	Hopper	1132	87	37	10765
			Season Total:		87	37	10765
			% of G.H. Population		0.00	0.30	3.43
			% of Local Area Population		0.00	0.02	2.85
1	Jun-Sep	Crossover	Hopper	1000	143	743	5499
1	Jun-Sep	Hoquiam	Pipeline	434	619	537	2775
			Season Total:		762	1280	8274
			% of G.H. Population		0.51	0.30	1.21
			% of Local Area Population		0.09	0.26	0.78
			Annual Total:		2253	3028	29502
2	Oct-Dec	Crossover	Hopper	250	143	215	1613
2	Oct-Dec	Moon Is.	Hopper	1786	1023	1536	11523
2	Oct-Dec	Hoquiam	Pipeline	916	2624	916	6872
2	Oct-Dec	Cow pt.Si	Pipeline	934	2675	934	7007
2	Oct-Dec	Cow pt.Gr	Pipeline	374	1071	374	2806
			Season Total:		7537	3976	29820
			% of G.H. Population		3.36	1.04	3.21
			% of Local Area Population		0.77	0.87	2.29
2	Jan-Mar	Crossover	Hopper	1000	1192	289	1300
2	Jan-Mar	Moon Is.	Hopper	714	851	206	928
2	Jan-Mar	Aberdeen	Pipeline	670	1996	225	1013
			Season Total:		4038	719	3240
			% of G.H. Population		1.39	0.45	0.93
			% of Local Area Population		0.39	0.31	0.44
2	Apr-May	Entrance	Hopper	330	25	11	3138
			Season Total:		25	11	3138
			% of G.H. Population		0.00	0.09	1.00
			% of Local Area Population		0.00	0.01	0.83
2	Jun-Sep	Outer bar	Hopper	2800	406	13765	90817
			Season Total:		406	13765	90817
			% of G.H. Population		0.27	3.27	13.26
			% of Local Area Population		0.05	2.78	8.59
			Annual Total:		12006	18471	127015
			Project Totals		14258	21499	156517

Table B11a: Entrainment (Number of Crabs)
Confined Disposal, Curved Entr.Function, Worst Population

Year	Season	Reach	Equipment	Vol.	Age Class 0+	1+	>1+
1	Jan-Mar	South	Hopper	1698	4356	2772	3036
			Season Total:		4356	2772	3036
			% of G.H. Population		0.11	0.68	0.49
			% of Local Area Population		0.10	0.35	0.22
1	Apr-May	South	Hopper	1132	240493	190186	181597
			Season Total:		240493	190186	181597
			% of G.H. Population		0.15	3.80	5.88
			% of Local Area Population		0.14	2.42	4.75
1	Jun-Sep	Crossover	Hopper	1000	49068	60148	13454
1	Jun-Sep	Hoquiam	Pipeline	434	21296	26104	5839
			Season Total:		70364	86253	19293
			% of G.H. Population		0.32	0.73	0.92
			% of Local Area Population		0.29	0.67	0.51
			Annual Total:		315213	279211	203926
2	Oct-Dec	Crossover	Hopper	250	80446	41972	26982
2	Oct-Dec	Moon Is.	Hopper	1786	574705	299846	192758
2	Oct-Dec	Hoquiam	Pipeline	916	294754	153784	98861
2	Oct-Dec	Cow pt.Si	Pipeline	934	300546	156806	100804
2	Oct-Dec	Cow pt.Gr	Pipeline	374	120347	62790	40365
			Season Total:		1370797	715198	459770
			% of G.H. Population		10.82	15.03	19.90
			% of Local Area Population		10.07	13.29	13.48
2	Jan-Mar	Crossover	Hopper	1000	2985	649	1947
2	Jan-Mar	Moon Is.	Hopper	714	2131	463	1390
2	Jan-Mar	Aberdeen	Pipeline	670	2000	435	1304
			Season Total:		7116	1547	4641
			% of G.H. Population		0.17	0.38	0.75
			% of Local Area Population		0.16	0.19	0.33
2	Apr-May	Entrance	Hopper	330	70108	55443	52939
			Season Total:		70108	55443	52939
			% of G.H. Population		0.04	1.11	1.71
			% of Local Area Population		0.04	0.70	1.39
2	Jun-Sep	Outer bar	Hopper	2800	426332	1828963	451912
			Season Total:		426332	1828963	451912
			% of G.H. Population		1.94	15.45	21.62
			% of Local Area Population		1.76	14.16	11.96
			Annual Total:		1874354	2601152	969262
			Project Totals		2189567	2880362	1173189

Table B11b: Immediate Dredge Mortality (Number of Crabs)
Confined Disposal, Curved Entr.Function, Worst Population

Year	Season	Reach	Equipment	Vol.	Age Class 0+	1+	>1+
1	Jan-Mar	South	Hopper	1698	1742	2384	2611
			Season Total:		1742	2384	2611
			% of G.H. Population		0.04	0.58	0.42
			% of Local Area Population		0.04	0.30	0.19
1	Apr-May	South	Hopper	1132	12025	114112	156173
			Season Total:		12025	114112	156173
			% of G.H. Population		0.01	2.28	5.05
			% of Local Area Population		0.01	1.45	4.09
1	Jun-Sep	Crossover	Hopper	1000	4907	36089	11571
1	Jun-Sep	Hoquiam	Pipeline	434	21296	26104	5839
			Season Total:		26202	62193	17410
			% of G.H. Population		0.12	0.53	0.83
			% of Local Area Population		0.11	0.48	0.46
			Annual Total:		39969	178689	176194
2	Oct-Dec	Crossover	Hopper	250	16089	36096	23204
2	Oct-Dec	Moon Is.	Hopper	1786	114941	257868	165772
2	Oct-Dec	Hoquiam	Pipeline	916	294754	153784	98861
2	Oct-Dec	Cow pt.Si	Pipeline	934	300546	156806	100804
2	Oct-Dec	Cow pt.Gr	Pipeline	374	120347	62790	40365
			Season Total:		846676	667344	429007
			% of G.H. Population		6.68	14.02	18.57
			% of Local Area Population		6.22	12.40	12.58
2	Jan-Mar	Crossover	Hopper	1000	1194	558	1674
2	Jan-Mar	Moon Is.	Hopper	714	853	398	1195
2	Jan-Mar	Aberdeen	Pipeline	670	2000	435	1304
			Season Total:		4047	1391	4174
			% of G.H. Population		0.10	0.34	0.67
			% of Local Area Population		0.09	0.17	0.30
2	Apr-May	Entrance	Hopper	330	3505	33266	45528
			Season Total:		3505	33266	45528
			% of G.H. Population		0.00	0.66	1.47
			% of Local Area Population		0.00	0.42	1.19
2	Jun-Sep	Outer bar	Hopper	2800	42633	1097378	388644
			Season Total:		42633	1097378	388644
			% of G.H. Population		0.19	9.27	18.60
			% of Local Area Population		0.18	8.49	10.28
			Annual Total:		896861	1799379	867352
			Project Totals		936831	1978068	1043547

Table B11c: Relative Loss at Age 2+ (Number of Crabs)
Confined Disposal, Curved Entr.Function, Worst Population

Year	Season	Reach	Equipment	Vol.	Age Class 0+	1+	>1+
1	Jan-Mar	South	Hopper	1698	47	529	2611
			Season Total:		47	529	2611
			% of G.H. Population		0.04	0.58	0.42
			% of Local Area Population		0.04	0.30	0.19
1	Apr-May	South	Hopper	1132	36	5706	49507
			Season Total:		36	5706	49507
			% of G.H. Population		0.01	2.28	5.05
			% of Local Area Population		0.01	1.45	4.09
1	Jun-Sep	Crossover	Hopper	1000	25	2959	5392
1	Jun-Sep	Hoquiam	Pipeline	434	106	2141	2721
			Season Total:		131	5100	8113
			% of G.H. Population		0.12	0.53	0.83
			% of Local Area Population		0.11	0.48	0.46
			Annual Total:		214	11335	60231
2	Oct-Dec	Crossover	Hopper	250	209	5162	16591
2	Oct-Dec	Moon Is.	Hopper	1786	1494	36875	118527
2	Oct-Dec	Hoquiam	Pipeline	916	3832	21991	70686
2	Oct-Dec	Cow pt.Si	Pipeline	934	3907	22423	72075
2	Oct-Dec	Cow pt.Gr	Pipeline	374	1565	8979	28861
			Season Total:		11007	95430	306740
			% of G.H. Population		6.68	14.02	18.57
			% of Local Area Population		6.22	12.40	12.58
2	Jan-Mar	Crossover	Hopper	1000	32	124	1674
2	Jan-Mar	Moon Is.	Hopper	714	23	88	1195
2	Jan-Mar	Aberdeen	Pipeline	670	54	97	1304
			Season Total:		109	309	4174
			% of G.H. Population		0.10	0.34	0.67
			% of Local Area Population		0.09	0.17	0.30
2	Apr-May	Entrance	Hopper	330	11	1663	14432
			Season Total:		11	1663	14432
			% of G.H. Population		0.00	0.66	1.47
			% of Local Area Population		0.00	0.42	1.19
2	Jun-Sep	Outer bar	Hopper	2800	213	89985	181108
			Season Total:		213	89985	181108
			% of G.H. Population		0.19	9.27	18.60
			% of Local Area Population		0.18	8.49	10.28
			Annual Total:		11340	187387	506454
			Project Totals		11554	198722	566685

Table B12a: Entrainment (Number of Crabs)
Confined Disposal, Curved Entr.Function, Mean Population

Year	Season	Reach	Equipment	Vol.	Age Class 0+	1+	>1+
1	Jan-Mar	South	Hopper	1698	17832	6506	4097
			Season Total:		17832	6506	4097
			% of G.H. Population		0.26	0.68	1.28
			% of Local Area Population		0.04	0.14	0.32
1	Apr-May	South	Hopper	1132	99296	34078	40541
			Season Total:		99296	34078	40541
			% of G.H. Population		0.05	1.06	2.90
			% of Local Area Population		0.04	0.45	1.45
1	Jun-Sep	Crossover	Hopper	1000	40345	20173	4362
1	Jun-Sep	Hoquiam	Pipeline	434	17510	8755	1893
			Season Total:		57855	28928	6255
			% of G.H. Population		0.24	0.42	0.47
			% of Local Area Population		0.03	0.17	0.19
			Annual Total:		174984	69512	50892
2	Oct-Dec	Crossover	Hopper	250	6451	1829	674
2	Oct-Dec	Moon Is.	Hopper	1786	46085	13069	4815
2	Oct-Dec	Hoquiam	Pipeline	916	23636	6703	2469
2	Oct-Dec	Cow pt.Si	Pipeline	934	24100	6834	2518
2	Oct-Dec	Cow pt.Gr	Pipeline	374	9650	2737	1008
			Season Total:		109923	31172	11484
			% of G.H. Population		0.91	0.87	0.98
			% of Local Area Population		0.13	0.33	0.46
2	Jan-Mar	Crossover	Hopper	1000	10543	1014	405
2	Jan-Mar	Moon Is.	Hopper	714	7527	724	290
2	Jan-Mar	Aberdeen	Pipeline	670	7064	679	272
			Season Total:		25133	2417	967
			% of G.H. Population		0.37	0.25	0.30
			% of Local Area Population		0.06	0.05	0.08
2	Apr-May	Entrance	Hopper	330	28947	9934	11819
			Season Total:		28947	9934	11819
			% of G.H. Population		0.01	0.31	0.84
			% of Local Area Population		0.01	0.13	0.42
2	Jun-Sep	Outer bar	Hopper	2800	209818	387664	143875
			Season Total:		209818	387664	143875
			% of G.H. Population		0.88	5.64	10.74
			% of Local Area Population		0.11	2.24	4.28
			Annual Total:		373821	431187	168145
			Project Totals		548805	500699	219037

Table B12b: *Immediate Dredge Mortality (Number of Crabs)*
Confined Disposal, Curved Entr. Function, Mean Population

Year	Season	Reach	Equipment	Vol.	Age Class 0+	1+	>1+
1	Jan-Mar	South	Hopper	1698	7133	5595	3523
			Season Total:		7133	5595	3523
			% of G.H. Population		0.10	0.58	1.10
			% of Local Area Population		0.02	0.12	0.28
1	Apr-May	South	Hopper	1132	4965	20447	34865
			Season Total:		4965	20447	34865
			% of G.H. Population		0.00	0.64	2.49
			% of Local Area Population		0.00	0.27	1.25
1	Jun-Sep	Crossover	Hopper	1000	4035	12104	3751
1	Jun-Sep	Hoquiam	Pipeline	434	17510	8755	1893
			Season Total:		21544	20859	5644
			% of G.H. Population		0.09	0.30	0.42
			% of Local Area Population		0.01	0.12	0.17
			Annual Total:		33642	46901	44032
2	Oct-Dec	Crossover	Hopper	250	1290	1573	580
2	Oct-Dec	Moon Is.	Hopper	1786	9217	11239	4141
2	Oct-Dec	Hoquiam	Pipeline	916	23636	6703	2469
2	Oct-Dec	Cow pt.Si	Pipeline	934	24100	6834	2518
2	Oct-Dec	Cow pt.Gr	Pipeline	374	9650	2737	1008
			Season Total:		67894	29086	10716
			% of G.H. Population		0.56	0.81	0.92
			% of Local Area Population		0.08	0.30	0.43
2	Jan-Mar	Crossover	Hopper	1000	4217	872	349
2	Jan-Mar	Moon Is.	Hopper	714	3011	622	249
2	Jan-Mar	Aberdeen	Pipeline	670	7064	679	272
			Season Total:		14291	2173	869
			% of G.H. Population		0.21	0.23	0.27
			% of Local Area Population		0.03	0.05	0.07
2	Apr-May	Entrance	Hopper	330	1447	5961	10164
			Season Total:		1447	5961	10164
			% of G.H. Population		0.00	0.19	0.73
			% of Local Area Population		0.00	0.08	0.36
2	Jun-Sep	Outer bar	Hopper	2800	20982	232599	123733
			Season Total:		20982	232599	123733
			% of G.H. Population		0.09	3.39	9.23
			% of Local Area Population		0.01	1.34	3.68
			Annual Total:		104615	269819	145482
			Project Totals		138257	316720	189515

Table B12c: Relative Loss at Age 2+ (Number of Crabs)
Confined Disposal, Curved Entr.Function, Mean Population

Year	Season	Reach	Equipment	Vol.	Age Class 0+	1+	>1+
1	Jan-Mar	South	Hopper	1698	193	1242	3523
			Season Total:		193	1242	3523
			% of G.H. Population		0.10	0.58	1.10
			% of Local Area Population		0.02	0.12	0.28
1	Apr-May	South	Hopper	1132	15	1022	11052
			Season Total:		15	1022	11052
			% of G.H. Population		0.00	0.64	2.49
			% of Local Area Population		0.00	0.27	1.25
1	Jun-Sep	Crossover	Hopper	1000	20	992	1748
1	Jun-Sep	Hoquiam	Pipeline	434	88	718	882
			Season Total:		108	1710	2630
			% of G.H. Population		0.09	0.30	0.42
			% of Local Area Population		0.01	0.12	0.17
			Annual Total:		315	3975	17205
2	Oct-Dec	Crossover	Hopper	250	17	225	414
2	Oct-Dec	Moon Is.	Hopper	1786	120	1607	2961
2	Oct-Dec	Hoquiam	Pipeline	916	307	958	1766
2	Oct-Dec	Cow pt.Si	Pipeline	934	313	977	1800
2	Oct-Dec	Cow pt.Gr	Pipeline	374	125	391	721
			Season Total:		883	4159	7662
			% of G.H. Population		0.56	0.81	0.92
			% of Local Area Population		0.08	0.30	0.43
2	Jan-Mar	Crossover	Hopper	1000	114	194	349
2	Jan-Mar	Moon Is.	Hopper	714	81	138	249
2	Jan-Mar	Aberdeen	Pipeline	670	191	151	272
			Season Total:		386	483	869
			% of G.H. Population		0.21	0.23	0.27
			% of Local Area Population		0.03	0.05	0.07
2	Apr-May	Entrance	Hopper	330	4	298	3222
			Season Total:		4	298	3222
			% of G.H. Population		0.00	0.19	0.73
			% of Local Area Population		0.00	0.08	0.36
2	Jun-Sep	Outer bar	Hopper	2800	105	19073	57659
			Season Total:		105	19073	57659
			% of G.H. Population		0.09	3.39	9.23
			% of Local Area Population		0.01	1.34	3.68
			Annual Total:		1378	24013	69413
			Project Totals		1693	27988	86618

Table B13a: Entrainment (Number of Crabs)
Confined Disposal, PL=33%, linear entr., mean population

Year	Season	Reach	Equipment	Vol.	Age Class 0+	1+	>1+
1	Jan-Mar	South	Hopper	1698	98085	35788	22533
				Season Total:	98085	35788	22533
				% of G.H. Population	1.43	3.73	7.04
				% of Local Area Population	0.24	0.76	1.77
1	Apr-May	South	Hopper	1132	149337	51252	60972
				Season Total:	149337	51252	60972
				% of G.H. Population	0.07	1.60	4.36
				% of Local Area Population	0.07	0.67	2.18
1	Jun-Sep	Crossover	Hopper	1000	100476	50238	10862
1	Jun-Sep	Hoquiam	Pipeline	434	14390	7195	1556
				Season Total:	114867	57433	12418
				% of G.H. Population	0.48	0.84	0.93
				% of Local Area Population	0.06	0.33	0.37
				Annual Total:	362288	144473	95923
2	Oct-Dec	Crossover	Hopper	250	22743	6449	2376
2	Oct-Dec	Moon Is.	Hopper	1786	162476	46075	16975
2	Oct-Dec	Hoquiam	Pipeline	916	27499	7798	2873
2	Oct-Dec	Cow pt.Si	Pipeline	934	28039	7951	2929
2	Oct-Dec	Cow pt.Gr	Pipeline	374	11228	3184	1173
				Season Total:	251985	71458	26327
				% of G.H. Population	2.09	2.00	2.25
				% of Local Area Population	0.30	0.75	1.06
2	Jan-Mar	Crossover	Hopper	1000	70605	6789	2716
2	Jan-Mar	Moon Is.	Hopper	714	50412	4847	1939
2	Jan-Mar	Aberdeen	Pipeline	670	15611	1501	600
				Season Total:	136628	13137	5255
				% of G.H. Population	1.99	1.37	1.64
				% of Local Area Population	0.33	0.28	0.41
2	Apr-May	Entrance	Hopper	330	43535	14941	17774
				Season Total:	43535	14941	17774
				% of G.H. Population	0.02	0.47	1.27
				% of Local Area Population	0.02	0.20	0.63
2	Jun-Sep	Outer bar	Hopper	2800	229499	424026	157371
				Season Total:	229499	424026	157371
				% of G.H. Population	0.97	6.17	11.74
				% of Local Area Population	0.12	2.45	4.68
				Annual Total:	661646	523563	206727
				Project Totals	1023934	668036	302650

Table B13b: Immediate Dredge Mortality (Number of Crabs)
Confined Disposal, PL=33%, linear entr., mean population

Year	Season	Reach	Equipment	Vol.	Age Class 0+	1+	>1+
1	Jan-Mar	South	Hopper	1698	39234	30777	19378
				Season Total:	39234	30777	19378
				% of G.H. Population	0.57	3.21	6.06
				% of Local Area Population	0.10	0.65	1.53
1	Apr-May	South	Hopper	1132	7467	30751	52436
				Season Total:	7467	30751	52436
				% of G.H. Population	0.00	0.96	3.75
				% of Local Area Population	0.00	0.40	1.87
1	Jun-Sep	Crossover	Hopper	1000	10048	30143	9342
1	Jun-Sep	Hoquiam	Pipeline	434	14390	7195	1556
				Season Total:	24438	37338	10897
				% of G.H. Population	0.10	0.54	0.81
				% of Local Area Population	0.01	0.22	0.32
				Annual Total:	71139	98866	82711
2	Oct-Dec	Crossover	Hopper	250	4549	5547	2043
2	Oct-Dec	Moon Is.	Hopper	1786	32495	39625	14599
2	Oct-Dec	Hoquiam	Pipeline	916	27499	7798	2873
2	Oct-Dec	Cow pt.Si	Pipeline	934	28039	7951	2929
2	Oct-Dec	Cow pt.Gr	Pipeline	374	11228	3184	1173
				Season Total:	103810	64105	23618
				% of G.H. Population	0.86	1.80	2.02
				% of Local Area Population	0.12	0.67	0.95
2	Jan-Mar	Crossover	Hopper	1000	28242	5838	2335
2	Jan-Mar	Moon Is.	Hopper	714	20165	4169	1667
2	Jan-Mar	Aberdeen	Pipeline	670	15611	1501	600
				Season Total:	64018	11508	4603
				% of G.H. Population	0.93	1.20	1.44
				% of Local Area Population	0.16	0.24	0.36
2	Apr-May	Entrance	Hopper	330	2177	8965	15286
				Season Total:	2177	8965	15286
				% of G.H. Population	0.00	0.28	1.09
				% of Local Area Population	0.00	0.12	0.55
2	Jun-Sep	Outer bar	Hopper	2800	22950	254416	135339
				Season Total:	22950	254416	135339
				% of G.H. Population	0.10	3.70	10.10
				% of Local Area Population	0.01	1.47	4.03
				Annual Total:	192954	338993	178846
				Project Totals	264093	437860	261557

Table B13c: Relative Loss at Age 2+ (Number of Crabs)
Confined Disposal, PL=33%, linear entr., mean population

Year	Season	Reach	Equipment	Vol.	Age Class 0+	1+	>1+
1	Jan-Mar	South	Hopper	1698	1059	6833	19378
			Season Total:		1059	6833	19378
			% of G.H. Population		0.57	3.21	6.06
			% of Local Area Population		0.10	0.65	1.53
1	Apr-May	South	Hopper	1132	22	1538	16622
			Season Total:		22	1538	16622
			% of G.H. Population		0.00	0.96	3.75
			% of Local Area Population		0.00	0.40	1.87
1	Jun-Sep	Crossover	Hopper	1000	50	2472	4353
1	Jun-Sep	Hoquiam	Pipeline	434	72	590	725
			Season Total:		122	3062	5078
			% of G.H. Population		0.10	0.54	0.81
			% of Local Area Population		0.01	0.22	0.32
			Annual Total:		1204	11432	41079
2	Oct-Dec	Crossover	Hopper	250	59	793	1461
2	Oct-Dec	Moon Is.	Hopper	1786	422	5666	10438
2	Oct-Dec	Hoquiam	Pipeline	916	357	1115	2054
2	Oct-Dec	Cow pt.Si	Pipeline	934	365	1137	2095
2	Oct-Dec	Cow pt.Gr	Pipeline	374	146	455	839
			Season Total:		1350	9167	16887
			% of G.H. Population		0.86	1.80	2.02
			% of Local Area Population		0.12	0.67	0.95
2	Jan-Mar	Crossover	Hopper	1000	763	1296	2335
2	Jan-Mar	Moon Is.	Hopper	714	544	925	1667
2	Jan-Mar	Aberdeen	Pipeline	670	421	333	600
			Season Total:		1728	2555	4603
			% of G.H. Population		0.93	1.20	1.44
			% of Local Area Population		0.16	0.24	0.36
2	Apr-May	Entrance	Hopper	330	7	448	4846
			Season Total:		7	448	4846
			% of G.H. Population		0.00	0.28	1.09
			% of Local Area Population		0.00	0.12	0.55
2	Jun-Sep	Outer bar	Hopper	2800	115	20862	63068
			Season Total:		115	20862	63068
			% of G.H. Population		0.10	3.70	10.10
			% of Local Area Population		0.01	1.47	4.03
			Annual Total:		3199	33032	89403
			Project Totals		4403	44464	130482

Table B14a: Entrainment (Number of Crabs)
Confined Disposal, PL=33%, curved Entr.Function, Mean Population

Year	Season	Reach	Equipment	Vol.	Age Class 0+	1+	>1+
1	Jan-Mar	South	Hopper	1698	17832	6506	4097
		Season Total:			17832	6506	4097
		% of G.H. Population			0.26	0.68	1.28
		% of Local Area Population			0.04	0.14	0.32
1	Apr-May	South	Hopper	1132	99296	34078	40541
		Season Total:			99296	34078	40541
		% of G.H. Population			0.05	1.06	2.90
		% of Local Area Population			0.04	0.45	1.45
1	Jun-Sep	Crossover	Hopper	1000	40345	20173	4362
1	Jun-Sep	Hoquiam	Pipeline	434	5778	2889	625
		Season Total:			46124	23062	4986
		% of G.H. Population			0.19	0.34	0.37
		% of Local Area Population			0.02	0.13	0.15
		Annual Total:			163252	63646	49624
2	Oct-Dec	Crossover	Hopper	250	6451	1829	674
2	Oct-Dec	Moon Is.	Hopper	1786	46085	13069	4815
2	Oct-Dec	Hoquiam	Pipeline	916	7800	2212	815
2	Oct-Dec	Cow pt.Si	Pipeline	934	7953	2255	831
2	Oct-Dec	Cow pt.Gr	Pipeline	374	3185	903	333
		Season Total:			71473	20269	7467
		% of G.H. Population			0.59	0.57	0.64
		% of Local Area Population			0.08	0.21	0.30
2	Jan-Mar	Crossover	Hopper	1000	10543	1014	405
2	Jan-Mar	Moon Is.	Hopper	714	7527	724	290
2	Jan-Mar	Aberdeen	Pipeline	670	2331	224	90
		Season Total:			20401	1962	785
		% of G.H. Population			0.30	0.20	0.25
		% of Local Area Population			0.05	0.04	0.06
2	Apr-May	Entrance	Hopper	330	28947	9934	11819
		Season Total:			28947	9934	11819
		% of G.H. Population			0.01	0.31	0.84
		% of Local Area Population			0.01	0.13	0.42
2	Jun-Sep	Outer bar	Hopper	2800	209818	387664	143875
		Season Total:			209818	387664	143875
		% of G.H. Population			0.88	5.64	10.74
		% of Local Area Population			0.11	2.24	4.28
		Annual Total:			330639	419829	163946
		Project Totals			493891	483475	213570

Table B14b: Immediate Dredge Mortality (Number of Crabs)
Confined Disposal, PL=33', curved Entr. Function, Mean Population

Year	Season	Reach	Equipment	Vol.	Age Class 0+	1+	>1+
1	Jan-Mar	South	Hopper	1698	7133	5595	3523
			Season Total:		7133	5595	3523
			% of G.H. Population		0.10	0.58	1.10
			% of Local Area Population		0.02	0.12	0.28
1	Apr-May	South	Hopper	1132	4965	20447	34865
			Season Total:		4965	20447	34865
			% of G.H. Population		0.00	0.64	2.49
			% of Local Area Population		0.00	0.27	1.25
1	Jun-Sep	Crossover	Hopper	1000	4035	12104	3751
1	Jun-Sep	Hoquiam	Pipeline	434	5778	2889	625
			Season Total:		9813	14993	4376
			% of G.H. Population		0.04	0.22	0.33
			% of Local Area Population		0.00	0.09	0.13
			Annual Total:		21910	41035	42764
2	Oct-Dec	Crossover	Hopper	250	1290	1573	580
2	Oct-Dec	Moon Is.	Hopper	1786	9217	11239	4141
2	Oct-Dec	Hoquiam	Pipeline	916	7800	2212	815
2	Oct-Dec	Cow pt.Si	Pipeline	934	7953	2255	831
2	Oct-Dec	Cow pt.Gr	Pipeline	374	3185	903	333
			Season Total:		29445	18183	6699
			% of G.H. Population		0.24	0.51	0.57
			% of Local Area Population		0.03	0.19	0.27
2	Jan-Mar	Crossover	Hopper	1000	4217	872	349
2	Jan-Mar	Moon Is.	Hopper	714	3011	622	249
2	Jan-Mar	Aberdeen	Pipeline	670	2331	224	90
			Season Total:		9559	1718	687
			% of G.H. Population		0.14	0.18	0.21
			% of Local Area Population		0.02	0.04	0.05
2	Apr-May	Entrance	Hopper	330	1447	5961	10164
			Season Total:		1447	5961	10164
			% of G.H. Population		0.00	0.19	0.73
			% of Local Area Population		0.00	0.08	0.36
2	Jun-Sep	Outer bar	Hopper	2800	20982	232599	123733
			Season Total:		20982	232599	123733
			% of G.H. Population		0.09	3.39	9.23
			% of Local Area Population		0.01	1.34	3.68
			Annual Total:		61433	258460	141283
			Project Totals		83343	299495	184047

Table B14c: Relative Loss at Age 2+ (Number of Crabs)
Confined Disposal, PL=33, Curved Entr. Function, Mean Population

Year	Season	Reach	Equipment	Vol.	Age Class 0+	1+	>1+
1	Jan-Mar	South	Hopper	1698	193	1242	3523
			Season Total:		193	1242	3523
			% of G.H. Population		0.10	0.58	1.10
			% of Local Area Population		0.02	0.12	0.28
1	Apr-May	South	Hopper	1132	15	1022	11052
			Season Total:		15	1022	11052
			% of G.H. Population		0.00	0.64	2.49
			% of Local Area Population		0.00	0.27	1.25
1	Jun-Sep	Crossover	Hopper	1000	20	992	1748
1	Jun-Sep	Hoquiam	Pipeline	434	29	237	291
			Season Total:		49	1229	2039
			% of G.H. Population		0.04	0.22	0.33
			% of Local Area Population		0.00	0.09	0.13
			Annual Total:		257	3494	16614
2	Oct-Dec	Crossover	Hopper	250	17	225	414
2	Oct-Dec	Moon Is.	Hopper	1786	120	1607	2961
2	Oct-Dec	Hoquiam	Pipeline	916	101	316	583
2	Oct-Dec	Cow pt.Si	Pipeline	934	103	323	594
2	Oct-Dec	Cow pt.Gr	Pipeline	374	41	129	238
			Season Total:		383	2600	4790
			% of G.H. Population		0.24	0.51	0.57
			% of Local Area Population		0.03	0.19	0.27
2	Jan-Mar	Crossover	Hopper	1000	114	194	349
2	Jan-Mar	Moon Is.	Hopper	714	81	138	249
2	Jan-Mar	Aberdeen	Pipeline	670	63	50	90
			Season Total:		258	381	687
			% of G.H. Population		0.14	0.18	0.21
			% of Local Area Population		0.02	0.04	0.05
2	Apr-May	Entrance	Hopper	330	4	298	3222
			Season Total:		4	298	3222
			% of G.H. Population		0.00	0.19	0.73
			% of Local Area Population		0.00	0.08	0.36
2	Jun-Sep	Outer bar	Hopper	2800	105	19073	57659
			Season Total:		105	19073	57659
			% of G.H. Population		0.09	3.39	9.23
			% of Local Area Population		0.01	1.34	3.68
			Annual Total:		750	22353	66359
			Project Totals		1007	25847	82973

APPENDIX C

EQUATIONS USED IN ENTRAINMENT CALCULATIONS

The methods by which we calculated estimates of dredging impact are somewhat complicated, and only a verbal description was presented in the main text. This appendix is intended to provide a more detailed understanding of the methods. Here, we present the calculations in a logical order in algebraic form, with a single example followed through the entire process. The example will be for the dredgin plan <u>without</u> confined disposal, for the mean population level, and using the linear entrainment function. The principal results for this example are summarized in Table 5.3; detailed results are in Appendix Table B3. Table C1 provides a summary of the notation used here.

The starting point of our calculations (Fig. 4.1) is estimates of crab population abundance (Section 4.2.1). Abundance estimates for locational strata are calculated either as total numbers for the stratum (l) in a given season (s) [N(l,s)] or as a density [D(l,s)]. These are related by the total area in the stratum [A(l)]:

$$N(l,s) = D(l,s) \times A(l).$$

As described in Section 2.2, the proportional representation [p(a,l,s)] of each age class (a = 0+, 1+, >1+) was calculated, and the age-specific number or density of crabs at a given location and season may be expressed respectively as

$$N(l,s) \times p(a,l,s) \text{ or}$$

$$D(l,s) \times p(a,l,s).$$

The second set of information needed for the calculation is the dredging schedule, expressed as the volume [thousands of cubic yards (kcy) of dewatered solids] dredged by a specific type of gear (g) in a specific location and season [V(l,s,g)].

To calculate crab loss from knowledge of the population abundance and

Table C1. Summary of notation.

Type of Variable	Notation	Description
Structural categories	a	Age class
	l	Location (sampling stratum)
	s	Season of year
	g	Dredge gear used
Population descriptors	D(l,s)	Total estimated crab density (no./ha) at location l in season s.
	N(l,s)	Total estimated crab abundance in stratum l in season s.
	p(a,l,s)	Proportion of age class a in the population at location l in season s.
	S(a,s)	Expected probability of natural survival to winter of the 2+ year for an individual in age class a, season s.
	A(l)	Area (ha) of stratum l.
Dredging schedule	V(l,s,g)	Volume dredged (kcy) at location l in season s by gear g.
Entrainment	e(l,s,g)	Entrainment rate (crabs per kcy dredged) at location l in season s for gear g.
	m(a,s,g)	Dredge mortality rate for age class a and gear g in season s.
Loss	E(a,l,s,g)	Number of crabs in age class a entrained by gear g at location l in season s.
	IL(a,l,s,g)	Immediate loss of age a crabs at location l in season s by gear g.
	RL(a,l,s,g)	Relative loss (equivalent to age 2+) of age a crabs at location l in season s by gear g.
	PL(a,s)	Percentage loss - yearly loss expressed as a percentage of the local area population of age class a during season s.

the dredging schedule, we need to also know entrainment rates and post-entrainment mortality rates. Entrainment rates for given location, season, and gear [e(l,s,g)] are calculated from either the linear or curved entrainment functions (Table 4.6, Fig. 4.2). Thus, hopper dredge entrainment rate for the linear function is:

$$e(l,s,g) = 0.285 \times D(l,s), \tag{C1a}$$

and for the curved function is:

$$e(l,s,g) = 0.000015 \times D(l,s)^{2.41}. \tag{C1b}$$

For a pipeline dredge, these rates are used; for a clamshell, these rates are multiplied by 0.05. Post-entrainment mortality rates [m(a,s,g)] vary with age, season, and dredge gear (Table 3.3).

We are now ready to calculate crab loss from a single piece of gear operating at a single location during a single season. The total number of crabs entrained will be the entrainment rate multiplied by the volume dredged, which is then apportioned among the age classes present:

$$E(a,l,s,g) = e(l,s,g) \times V(l,s,g) \times p(a,l,s). \tag{C2}$$

To obtain the immediate loss (IL) from this, we multiply by the post-entrainment mortality:

$$IL(a,l,s,g) = E(a,l,s,g) \times m(a,s,g). \tag{C3}$$

Then, to express relative loss (equivalent to age 2+ crab), we multiply IL by the expected survival to age 2+ for the given age class in the given season:

$$RL(a,l,s,g) = IL(a,l,s,g) \times S(a,s). \tag{C4}$$

As an example of the calculation to this point, consider the effect of a hopper dredge operating in the South Reach of the channel during the winter (January-March) of the first construction year (first line in Table B3a). At this location and season, for the mean population, there is a total crab density of 324 crab/ha (Table 4.4). The linear entrainment function (Eq.

C1a) predicts an entrainment rate of 92.3 crab/kcy. There are 1698 kcy scheduled to be dredged, so total entrainment would be about 157,000 crabs. Age class proportions [p(a,1,s)] can be calculated (from Table 4.4) as follows: 0+ age class, p = 203/324 = 0.627; 1+ age class, p = 74/324 = 0.228, and >1+ age class, p = 47/324 = 0.145. Thus, applying Eq. C2, entrainment will be about 98,000 0+ crab, 36,000 1+ crab, and 23,000 >1+ crab (see Table B3a, first line). (Note that figures in Table 4.4 are rounded, so calculations from them will not exactly match the results given in Appendix B.) For 0+ crab in winter, hopper mortality will be 40% (Table 3.3), so immediate loss (Eq. C3) of 0+ crab will be about 39,000. Similarly, IL for 1+ crab is about 31,000, and for >1+ crab is about 19,000 (Table B3b, first line). To obtain relative loss (Eq. C4), IL values are multiplied by the expected survivals to age 2+ [S(a,s)]. (These survivals, calculated using a 5% survival rate for the 0+ year and Eq. 5 of Section 2.5.3 for older crab, are tabulated in Table C2.) Relative loss is then about 1000 (39,000 x 0.027) for 0+ crab, about 7000 (31,000 x 0.222) for 1+ crab, and about 19,000 (19,000 x 1.000) for >1+ crab (Table B3c, first line).

Table C2. Expected percent of crabs surviving to winter of the 2+ year for individuals in specific age classes and specific seasons.

	Age Class		
Season	0+	1+	>1+
Apr - May	0.3	5.0	31.7
Jun - Sep	0.5	8.2	46.6
Oct - Dec	1.3	14.3	71.5
Jan - Mar	2.7	22.2	100.0

If these calculations are repeated for every combination of season, reach and gear in each project year, annual total losses may be obtained. In the example, during project year 1, dredging by two gear types (hopper and

clamshell) occurs over three seasons (winter through summer) in three reaches (South, Crossover, and Hoquiam). For the 0+ age class, first year entrainment, immediate loss, and relative loss are about 383,000, 60,000, and 1000 crab, respectively (Table B3a, b, c). The values for immediate loss and relative loss appear in the two parts of Table 5.3 (under linear entrainment for the mean population).

Loss can also be expressed as a percentage of the local area population (Table 4.3) for each age class. Percentage loss for an age class in a season [PL(a,s)] is obtained by dividing immediate loss by the local population of that age class. In the example, for 0+ crab loss during winter of the first project year, IL is 39,000 (Table B3b) and local population is 41.2 million (Table 4.3), so PL is about 0.1% (Table B3b). [In Appendix B, loss is also expressed as a percentage of the Grays Harbor (G.H.) population, excluding the nearshore area.] These percentages may then be summed across seasons to obtain approximate annual percentage loss, as given in Tables 5.3 and 5.4.